SEWAGE AND INDUSTRIAL WASTES

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

ANNUAL CONVENTION NUMBER

Special Features

Sludge Filtration—Bargman et al.

Oxygen-Sag Equation—Wastler and Wastler

Radiophosphorus and Digestion—Grune et al.

Citrus Waste Utilization—Dougherty and McNary

Sedimentation Theory—Muszkalay and Vágás

Operator's Corner

Operating Data; Sewage and Poultry Waste Treatment

Program—Page 1201

Thirty-First Annual Meeting—Oct. 6–9, 1958

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SEPTEMBER 1958—VOL. 30, No. 9

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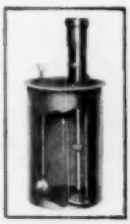

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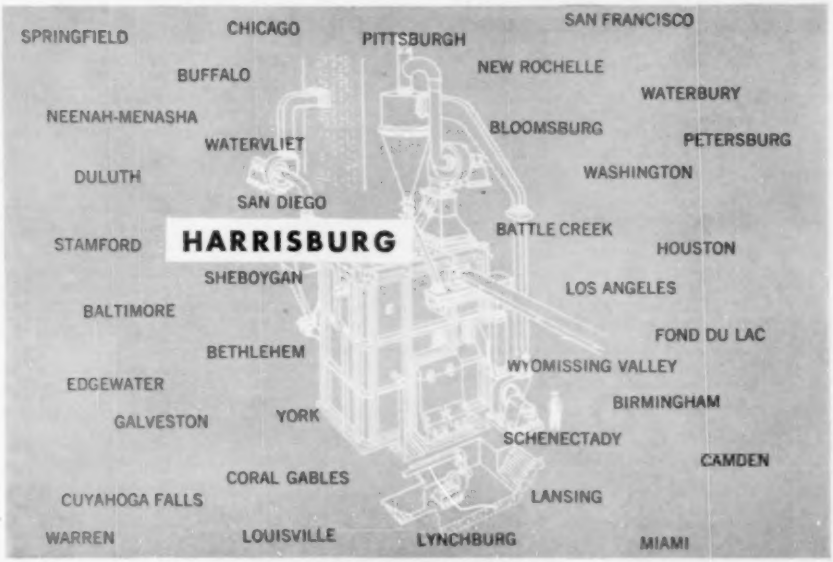

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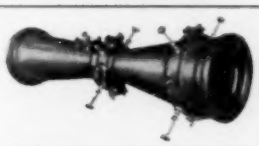
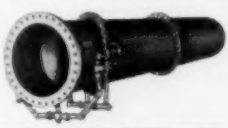
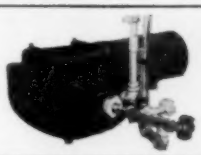
NORMAL SEWAGE, SLUDGE, TRADE WASTES		TYPE VS—FOUR TAP VENTURI TUBES Four cleaning valves at main and throat can be operated manually, by air, or hydraulically to keep piezometer holes clear for top accuracy. Two hand holes on each pressure belt and inspection opening at throat. BULLETIN 005
LOW-VELOCITY SEWAGE, HEAVY WASTES		TYPE VE—ELLIPTICAL VENTURI TUBES Developed specifically to accurately measure low-velocity sewage, sludge and heavy trade wastes—under low pressures. *Flat top* prevents air binding. *Flat bottom* is self-scouring. Inspection opening at throat. BROCHURE
LOW-HEAD SEWAGE, SLUDGE, TRADE WASTES		TYPE S—PARABOLIC FLUMES Full 20:1 range for open flows. Accuracy ±2%. Flanged, bell or spigot inlet for 6 to 36" lines. Integral sediment trap, piezometer reamer, gauge glass, direct-reading flow scale. BULLETIN 801

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Association	*Place*	*Time*
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South Dakota Water and Sewage Works Conf.	Franklin Hotel Deadwood, S. Dak.	Sept. 17–19, 1958
Kentucky-Tennessee Industrial Wastes and Sewage Works Assn.	Hotel Peabody Memphis, Tenn.	Sept. 22–24, 1958
Oklahoma Water, Sewage and Industrial Wastes Conf. (Industrial Wastes Conf.)	Oklahoma State Univ. Stillwater, Okla.	Sept. 24–25, 1958
Pacific Northwest Sewage and Industrial Wastes Assn.	Davenport Hotel Spokane, Wash.	Sept. 25–27, 1958
Missouri Water and Sewerage Conf.	Hotel Governor Jefferson City, Mo.	Sept. 28–30, 1958
North Dakota Water and Sewage Works Conf.	Ray Hotel Dickenson, N. Dak.	Oct. 1–3, 1958

THIRTY-FIRST ANNUAL MEETING

Federation of Sewage and Industrial Wastes Associations
in conjunction with
Michigan Sewage and Industrial Wastes Association
Sheraton-Cadillac Hotel, Detroit, Michigan
October 6–9, 1958

Florida Sewage and Industrial Wastes Assn.	Golden Gate Hotel N. Miami Beach, Fla.	Oct. 19–22, 1958
Canadian Institute on Sewage and Sanitation	Chateau Frontenac Quebec City, Que., Can.	Oct. 19–22, 1958
West Virginia Sewage and Industrial Wastes Assn.	Daniel Boone Hotel Charleston, W. Va.	Oct. 22–23, 1958
New England Sewage and Industrial Wastes Assn.	Statler Hilton Hotel Hartford, Conn.	Nov. 5–6, 1958
Nebraska Sewage and Industrial Wastes Assn.	Lincoln Hotel Lincoln, Nebr.	Nov. 6–7, 1958
North Carolina Sewage and Industrial Waste Assn.	Hotel O'Henry Greensboro, N. C.	Nov. 10–12, 1958

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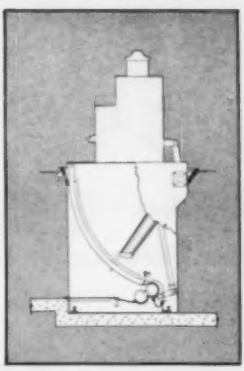

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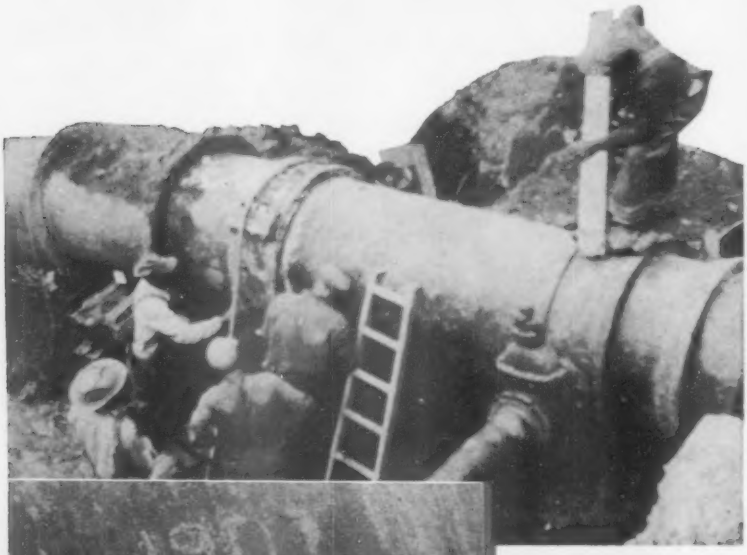

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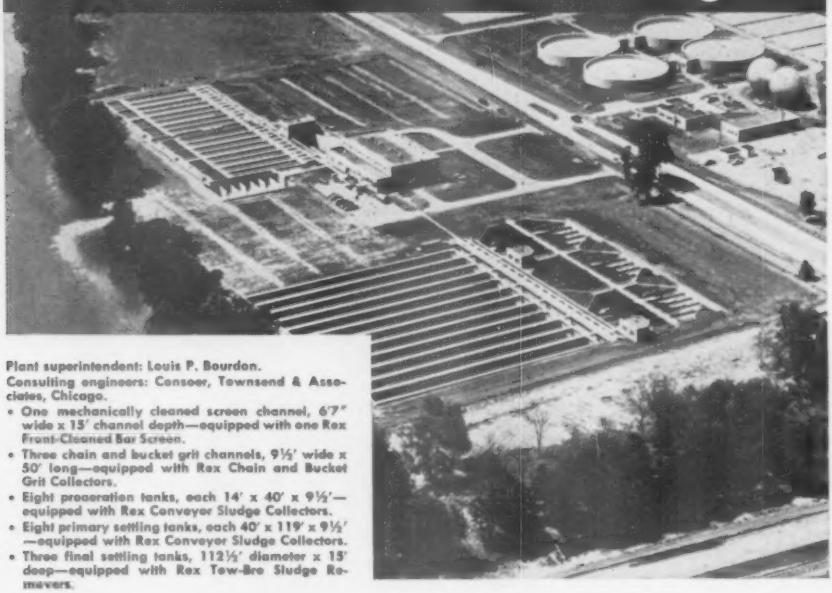

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- One mechanically cleaned screen channel, 6'7" wide x 15' channel depth—equipped with one Rex Front-Cleaned Bar Screen.
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- Eight preaeration tanks, each 14' x 40' x 9½'—equipped with Rex Conveyor Sludge Collectors.
- Eight primary settling tanks, each 40' x 119' x 9½'—equipped with Rex Conveyor Sludge Collectors.
- Three final settling tanks, 112½' diameter x 15' deep—equipped with Rex Tow-Bro Sludge Removers.

The South Bend, Indiana, sewage treatment plant is a model plant design and operation. This plant, which recently went into operation, is designed to function both as a conventional activated sludge and a split activated sludge treatment plant. It processes an average daily flow of 48 m.g.d. Optimum flexibility in treatment and operation was designed into this plant which can partially treat a peak flow to 80 m.g.d. To assure translation of design efficiencies into actual performance... provide maximum operating economy, CHAIN Belt's modern waste treatment equipment was installed in both the primary and secondary treatment stages.

A Rex Front-Cleaned Bar Screen and Rex Grit Collectors provide effective removal of large and inorganic solids. Rex Conveyor Sludge Collectors in the preaeration and primary settling tanks assure efficient preliminary treatment, and positive sludge and scum removal. Rex Tow-Bro Sludge Removers in the final sedimentation tanks provide the positive, gentle sludge removal so important in handling the light, "tricky" sludges encountered in the conventional and split activated sludge treatment processes.

Modern, performance-proved CHAIN Belt equipment and the broad experience of CHAIN Belt engineers provide the right combination for most effective results and maximum operating economies. For information on the complete line of Rex Sanitation Equipment, write CHAIN Belt Company, 4606 W. Greenfield Ave., Milwaukee 1, Wisconsin.

CHAIN BELT

Specify IOWA for every job

Iowa's complete line of valves for treatment plants assures you of efficient operation, low maintenance cost, and replacement parts when needed in years to come.

IOWA CHECK VALVES—Swing gate type for use in either horizontal or vertical pipe lines. Bronze trimmed throughout. Stainless steel hinge pins. Leather or rubber faced gates, or solid bronze, as desired—aluminum gates available for air service.

IOWA MEDIUM AND LOW PRESSURE VALVES—either non-rising stem or outside screw and yoke types. Designed as carefully as those conforming to A.W.W.A. specifications but with lighter construction for lower pressures.

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IOWA FLAP VALVES—all iron; can be furnished with bronze hinge bolts or fully bronze mounted—including bronze bolts, flap ring and seat ring—when required.

CLOW HYDROSTATIC RELIEF VALVES — commonly used in bottom of concrete tanks to prevent ground water from floating the tank. Close-grained cast iron body and lid; lead seat ring and lid ring. Cast iron grate in bottom prevents foreign matter from entering tank.

IOWA PLUG DRAIN VALVES—either rising or non-rising stem type. High strength cast iron bodies; bronze stem, operating nut, disc ring and seat ring; rustproof steel bolts and nuts. Handwheels, extension stems, plain or indicating floor stands if required.

IOWA SLUICE GATES—can be used in lines having both seating and unseating pressures. High strength cast iron, bronze mounted, with solid bronze adjustable wedges. Can be equipped with cylinder or motor unit for automatic operation.

IOWA SHEAR GATES—either all iron or iron, bronze mounted. Gate-seating wedges bolted on, permitting replacement without replacing frame.

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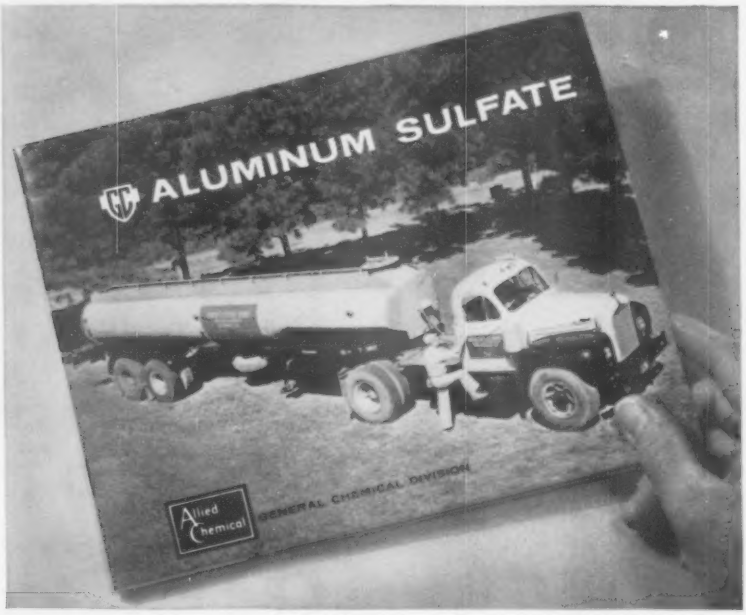

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Curbing pollution of Biscayne Bay

LINK-BELT equipment mechanizes sludge collection and disposal at new sewage treatment plant

Miami's recent, rapid growth has multiplied the pollution problem throughout its bay area—crimping such activities as swimming, boating, water skiing and fishing. Miami has met this threat to its tourist economy with construction of a $27,000,000 sewage disposal project.

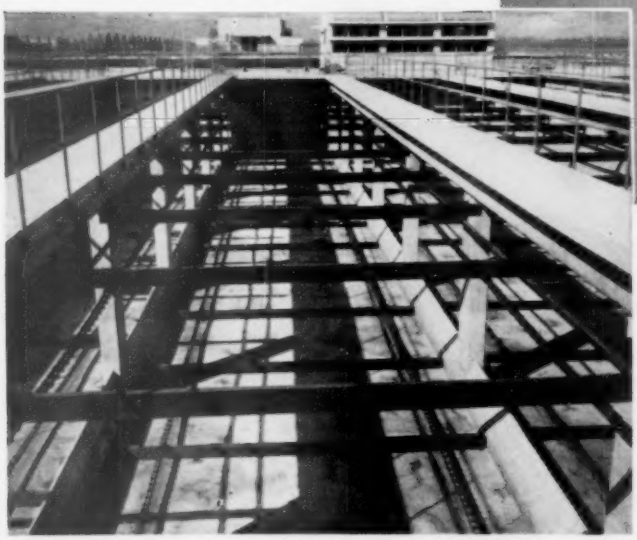
Inside and out, Miami's new activated sludge treatment plant utilizes sanitary engineering equipment by Link-Belt. A system of grit collectors with conveying screws and sludge collectors assists in low-cost treatment of sewage. Link-Belt bucket elevators carry liquid sludge to filters and belt conveyor . . . team up for efficient handling of the dewatered sludge. And Link-Belt Gearmotors and P.I.V. drives provide dependable power transmission for such equipment.

Link-Belt's complete line of equipment and broad engineering experience assure economical, effective water, sewage and waste treatment for municipalities and industries throughout the nation. A call to your nearest Link-Belt office will put you in touch with sanitary engineers who will work with your consultants and chemists.

LINK-BELT

SANITARY ENGINEERING EQUIPMENT

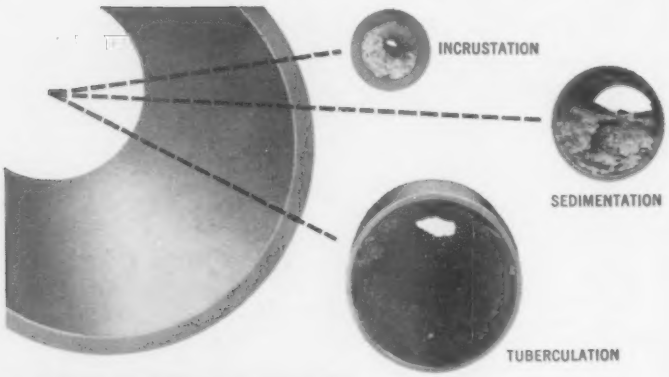
▲ **COMPLETE CONTROL PROJECT** provides interceptors, force mains and deep outfall line to deliver sewage to the Virginia Key activated sludge plant and to discharge plant effluent 4,600 feet out into the ocean. Design engineers were Rader Engineering Associates, Metcalf & Eddy and Maurice H. Connell and Associates, Inc.



◀ **BY THE DOZEN** — Here is just one of twelve Link-Belt Straightline sludge collectors operating in primary settling tanks at Miami's new plant. Sixteen Link-Belt Gearmotors drive sludge collectors and cross conveyors.

LINK-BELT COMPANY: Executive Offices, Prudential Plaza, Chicago 1. Sanitary Engineering Regional Offices—Colmar, Pa., Chicago 9, Kansas City 8, Mo., San Francisco 24. Sales Offices in All Principal Cities. Export Office, New York 7. Representatives Throughout the World. 14,914

See our exhibit—Federation of Sewage and Industrial Wastes Association, October 5-9, Detroit, Michigan.



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National knows how to work quickly reducing supplementary labor costs and service interruptions.

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National knows how to clean so thoroughly that restoration of 95% of the original pipe capacity is guaranteed.

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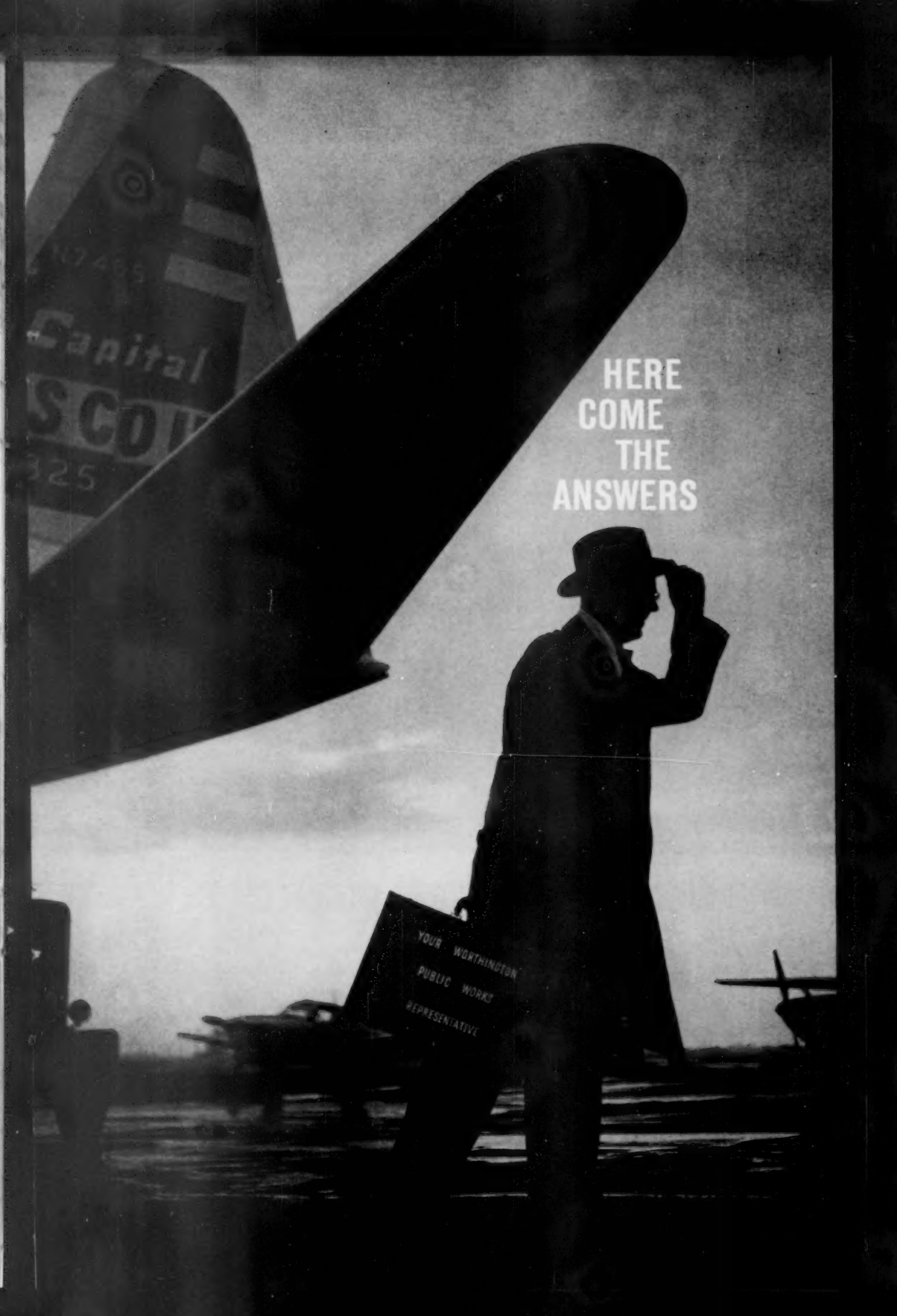
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PUBLIC WORKS
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Worthington's vast reservoir of Public

In Public Works there is no adequate substitute for experience. Worthington's experience in this essential field dates back to 1854 when the company's founder installed his first municipal water works pumps at Savannah, Georgia. Others soon followed. A duplex pump was installed at Charlestown, Massachusetts in 1863. Pumping engines were installed in Fort Worth, Texas in 1893. Twelve triple-expansion engines were put in at Philadelphia, Pennsylvania in 1908. Now the list is almost endless. There is hardly a municipality in the United States today that does not have a Worthington pump, compressor, engine or comminutor in service. This vast, cumulative experience and know-how proves invaluable year-in, year-out to communities in search of the very finest in service and equipment.

Key personnel in Worthington's Public Works Department have a combined experience in all phases of water and sewage plants of over 100 years.

Works experience is at your service

NATION-WIDE EXPERIENCE

Public Works representatives from Worthington criss-crossed the nation during 1957 bringing their knowledge to hundreds of municipalities. In so doing, they increased their skills by solving scores of local problems on equipment selection and application.

EXTENSIVE PRODUCT EXPERIENCE

Worthington makes a complete line of specialized equipment for water and sewage works. These are Worthington's basic products and the year they were introduced: Pumps (1840), Compressors (1893), Engines (1896), and Comminutors (1948).

REGIONAL REPRESENTATION

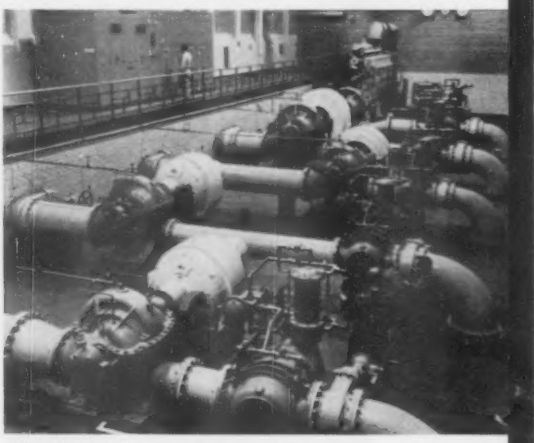
A network of Worthington Offices spans the nation, from New England to California, from Canada to Mexico. Staffed with experts trained in every phase of Public Works, these offices are your assurance of the best possible equipment and the finest possible application.

THE 4 BASIC SERVICES
of Worthington's Public Works Department

PLANNING Worthington experts will assist your consulting engineers in planning water and sewage plants. This coordinated planning care is why so many Worthington users report such long, outstandingly trouble-free operations.

EQUIPMENT COORDINATION Every municipality is different. No two systems are alike. That's why equipment must be versatile and coordinated. Because Worthington makes so wide a range of equipment, the most complex problems are quickly solved without compromising effectiveness of the system in any way.

EQUIPMENT SELECTION Because Worthington designs and manufactures a complete line of equipment, a Public Works Representative can make a substantial contribution to the operation of every plant. Using Worthington equipment limits your supply responsibility – makes for greater plant efficiency and integration.

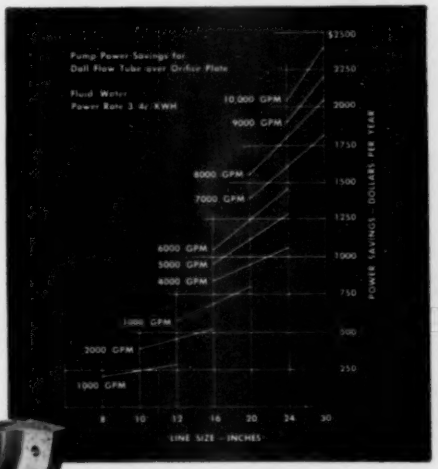


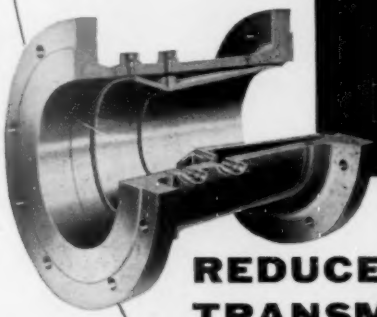
INSTALLATION Public Works specialists are few and far between. Worthington is fortunate in having so many on its staff. They will work with your consulting or contracting engineer in solving installation problems of equipment. It's the soundest way to build *dependability* in your systems.

WORTHINGTON

For illustrated brochure on Worthington's Public Works Department; or address of your nearest Worthington District Office, write: Worthington Corporation, Section 105-3, Harrison, New Jersey.

POSITIVE CONTROL OF MATERIALS IN MOTION BIF METERS FEEDERS CONTROLS





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Dall Flow Tubes offer unsurpassed pressure recovery . . . greatly reduced pumping costs over extended periods . . . plus adequate line pressure at distant points. Annual pump power savings can be approximated by entering chart at bottom (at desired line size) . . . tracing vertically to sloping flow line (maximum capacity) . . . and reading actual dollar savings directly opposite this intersection at right of chart.

In addition, the low-priced, performance-proved Dall Flow Tube cuts initial, installation, and operating costs . . . and provides a constant, stable discharge coefficient over a wide range. KEEP YOUR HEAD, save your money, by requesting free copy of Technical Bulletin 115-L3C today! Write **Builders-Providence, Inc., 368 Harris Ave., Providence 1, Rhode Island.**

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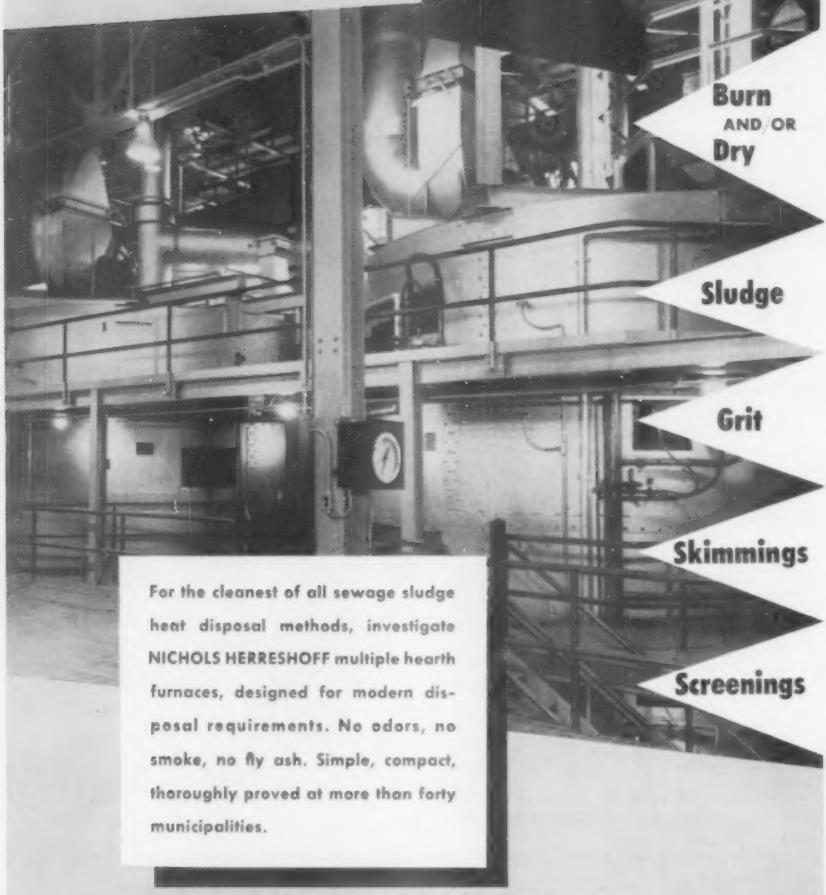
B-I-F INDUSTRIES BIF METERS FEEDERS CONTROLS

Nichols Herreshoff . .

for complete sewage disposal in . . . furnace



Burn AND/OR Dry

Sludge

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For the cleanest of all sewage sludge heat disposal methods, investigate NICHOLS HERRESHOFF multiple hearth furnaces, designed for modern disposal requirements. No odors, no smoke, no fly ash. Simple, compact, thoroughly proved at more than forty municipalities.

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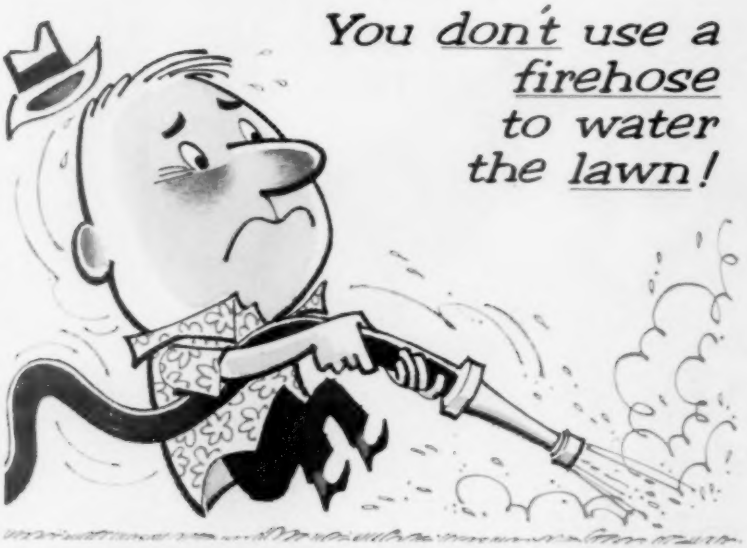

Nor need you any longer use a pipe that is not engineered to your specific requirements

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Concrete Pressure Pipe

Because if, for example, the installation calls for a maximum pressure of 35 pounds, Cen-Vi-Ro Concrete Pipe can be designed for this particular pressure. The dollars saved can be put to better use elsewhere!

The simplicity and precision of the Cen-Vi-Ro joint assure faster installation under all conditions. This results in substantial savings in laying costs as well.

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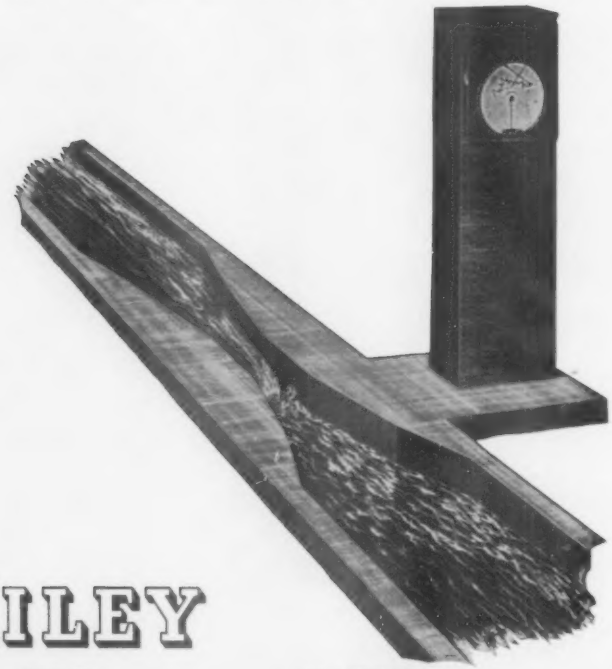

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For further information on how Bailey Meters can meet your needs, ask for Bulletin M22-5.

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Meters and Controls for Sewage and Water

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YEOMANS MANUFACTURES THE MOST COMPLETE LINE OF APPLICATION-DESIGNED SEWAGE TREATMENT EQUIPMENT

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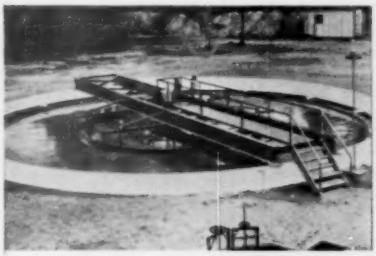

. . **SPIRAFLO CLARIFIER** for both primary and final clarification of domestic and process wastes. A clarifier of radically different design, the Spirafio offers complete settleable solids removal; greater removal of finely divided particles; positive grease, scum oil removal; uniform velocity throughout tank; and straight wall design which reduces construction costs.

. . the **CAVITATOR**, a newly developed Yeomans unit for low cost treatment of both domestic sewage and industrial wastes. Perfectly suited for small communities, subdivisions, motels, resorts, schools and industrial plants, the Cavitator has excellent purification efficiency, extremely high oxygen transfer efficiency, and extremely low air requirements per pound of B.O.D. removed.

. . the **WATER-WHEEL**, a rotary distributor used with trickling filter systems in the secondary treatment of sewage. An exceptionally rugged, yet simple piece of equipment, the Water-wheel provides uniform distribution over the entire filter bed at all flow rates . . even the lowest. Costly accessories such as underground feed pipe, dosing chamber with siphon, center support, and mercury seal are not required.

. . **YEOMANS ROTARY DISTRIBUTORS** (both standard rate and high capacity). Standard rate units distribute evenly across the entire filter bed . . adjustable nozzles produce fine, well-aerated spray which carries down high volumes of oxygen. For high capacity filters both the Yeomans high capacity type distributor, and the Aero-Filter system are avilable.

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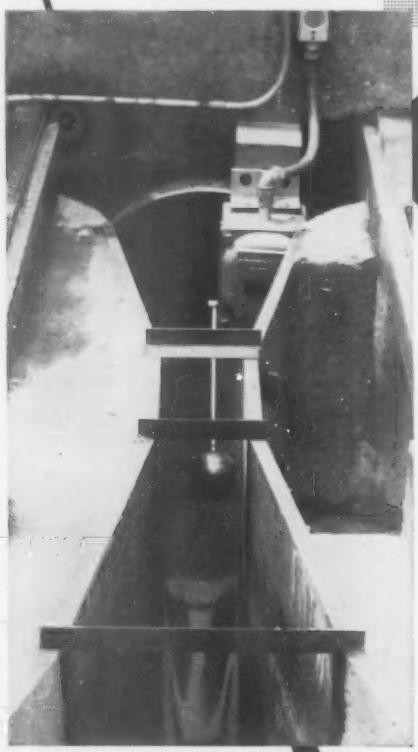
...A New Concept in Measuring Flow

Through Parshall Flumes



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The BURGESS-MANNING Type "ML" METER

Completely eliminates

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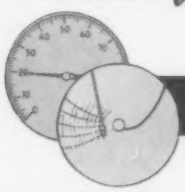

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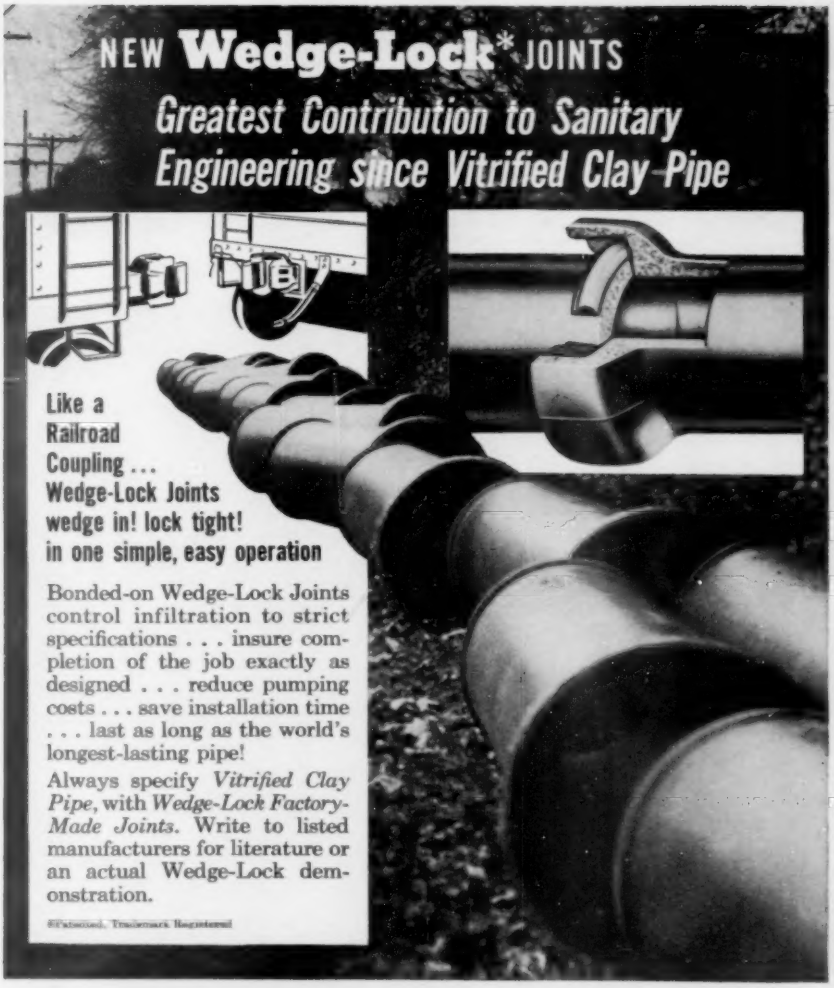
Instrumentation and Controls for water, steam, gases, sewage and industrial wastes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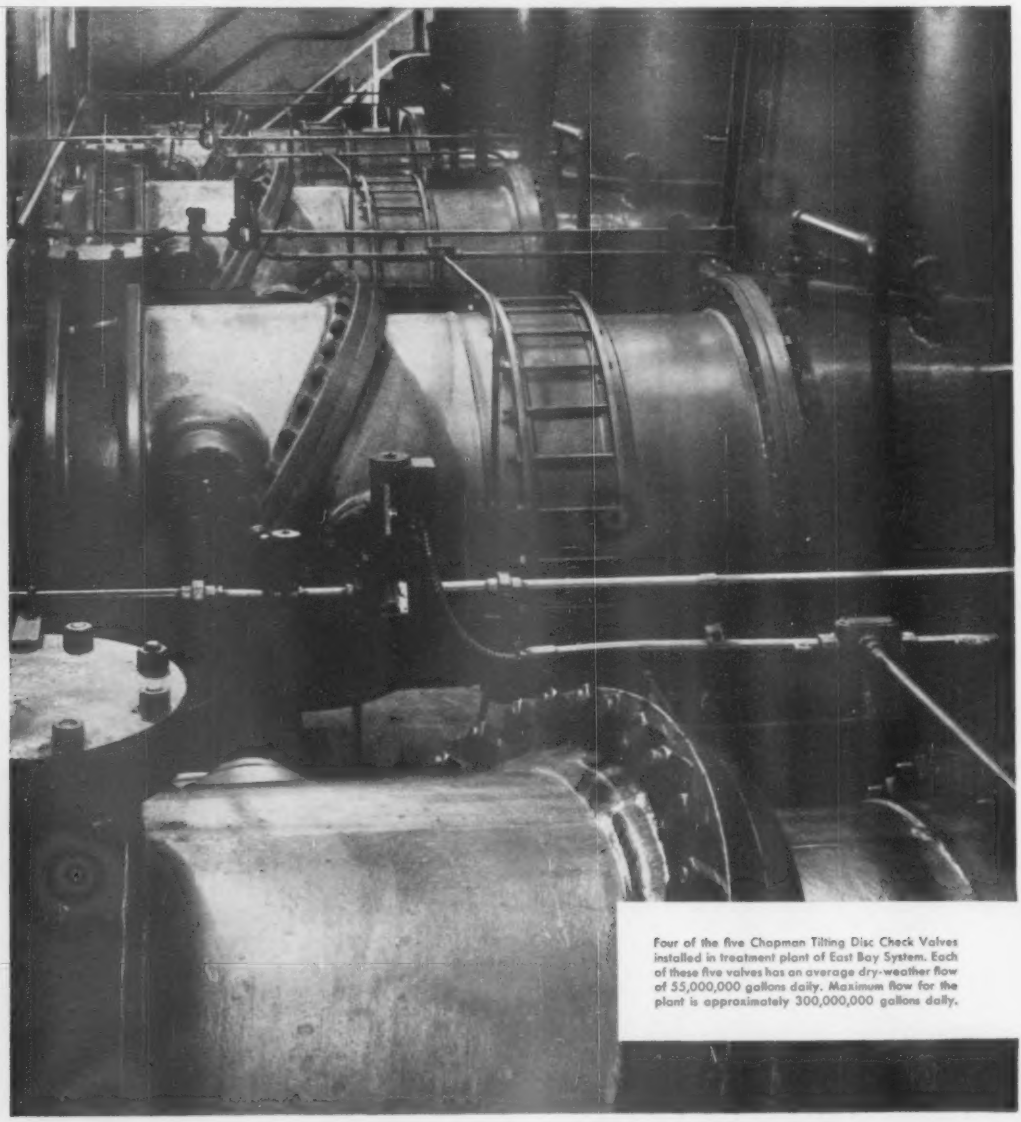
Superior Clay Corporation, Uhrichsville, Ohio
The Stillwater Clay Products Company, Cleveland 16, Ohio

In Oakland, California,

Main entrance to the East Bay Pumping Station. Engineering and erection of the entire sewage system was handled by the East Bay Municipal Utility District Engineering Staff.



Four of the five Chapman Tilting Disc Check Valves installed in treatment plant of East Bay System. Each of these five valves has an average dry-weather flow of 55,000,000 gallons daily. Maximum flow for the plant is approximately 300,000,000 gallons daily.

55 million gallons per day flow quietly through five trouble-free

CHAPMAN

TILTING DISC

CHECK VALVES

In Oakland, California, the East Bay Sewage Disposal System serves the cities of Oakland, Berkeley, Alameda, Albany, Emeryville and Piedmont. And it serves them well. It has improved health conditions and property values in the large East Bay area.

Representing an investment of $23,500,000 this system is modern in every respect. Twenty-one miles of reinforced concrete pipe bring sewage from six cities to the central treatment plant. At the treatment plant sewage is immediately chlorinated for odor control then raised 35 feet by five 42-inch pumps to the Grit Chambers from where it can flow by gravity through the rest of the system.

Finely screened sewage is pumped up through five 42-inch Chapman Tilting Disc Check Valves to prevent any return of the sewage to the Interceptors. Today, the average flow through these five valves is 55,000,000 gallons per day, with some variations. Yet, no matter how much it varies these Chapman Valves handle the flow quietly . . . no flutter, no slamming, no banging, no damage to valve or system. The valves automatically adjust themselves to the volume of the flow.

Chapman Tilting Disc Check Valves were the first with this unique design, engineered to meet standard and unusual conditions of service. Chapman know-how is one of the many reasons why its valves and control equipment are selected for installations of all kinds. Write, and one of our engineers will tell you more of the ways and whys.

Left: — Chapman Tilting Disc Check Valve with 6" bypass connection similar to the Chapman Check Valves installed in the East Bay Sewage Disposal System.

Why not send for our free Catalog No. 30-B showing and giving full information on all Chapman Tilting Disc Check Valves.

The **CHAPMAN** *Valve Manufacturing Company*

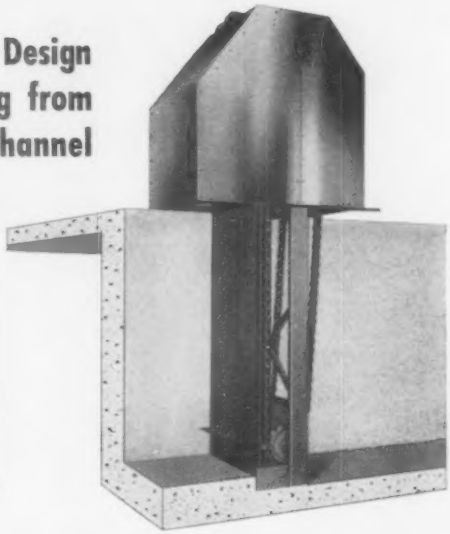
INDIAN ORCHARD, MASSACHUSETTS

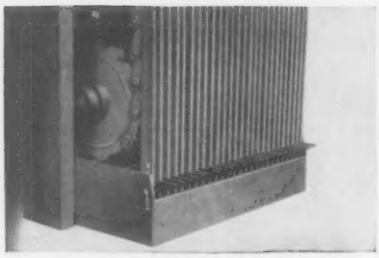
For over 75 years, Chapman has devoted its entire facilities to the valves of today and tomorrow. Chapman has the engineers, metallurgists, experience and manufacturing facilities to design, develop, build and test the valve equipment you need no matter how tough the requirements.

COMPLETELY AUTOMATIC MECHANICALLY CLEANED

UNIT BAR SCREEN

Exclusive Pivoted Rake Design Assures Positive Raking from Absolute Bottom of Channel





Horizontal position of rake teeth at the beginning of cleaning cycle accomplishes raking from absolute bottom of channel. Gets under and picks up all screenings—does not push them away • Note unobstructed channel approach.

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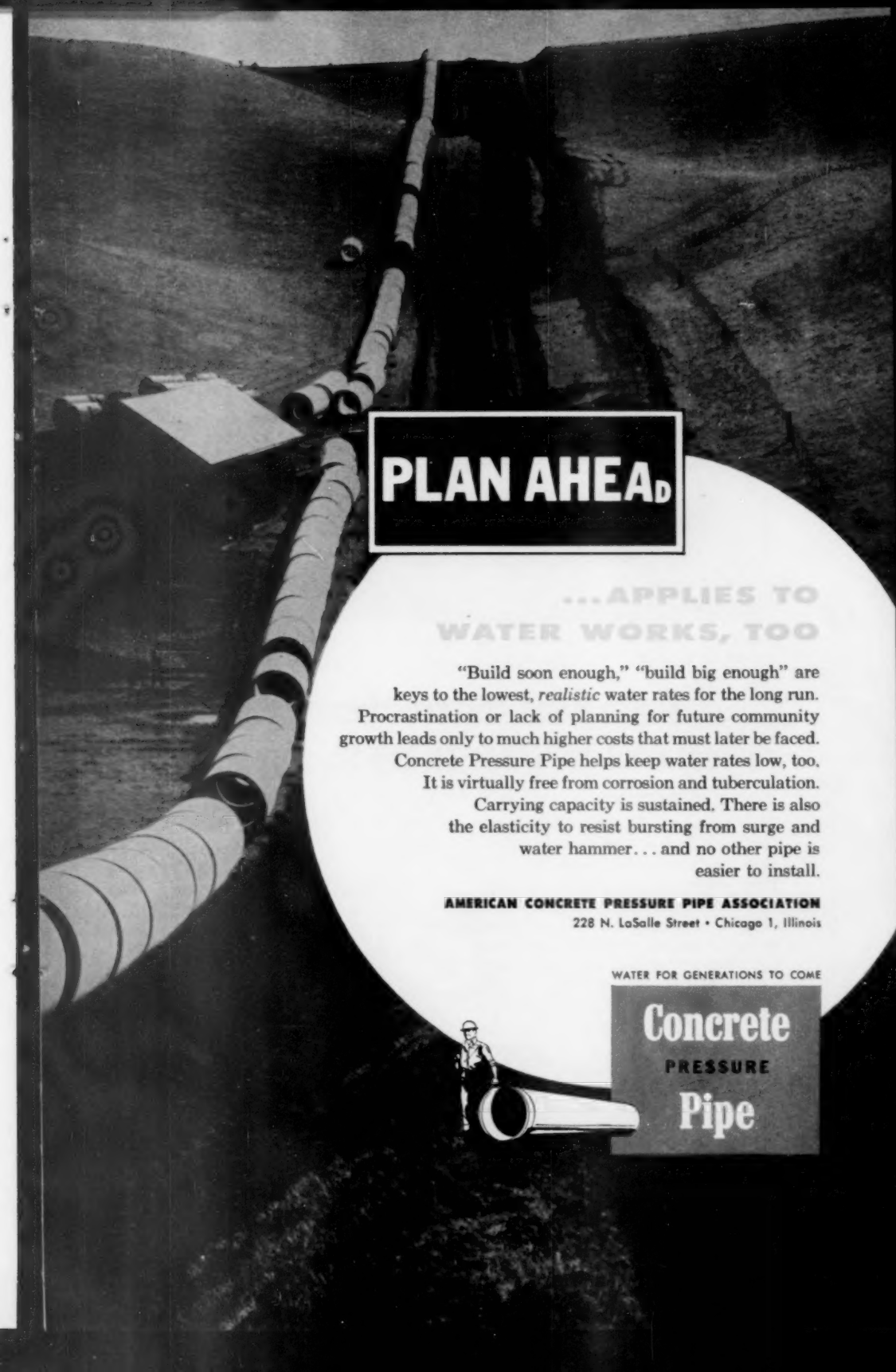
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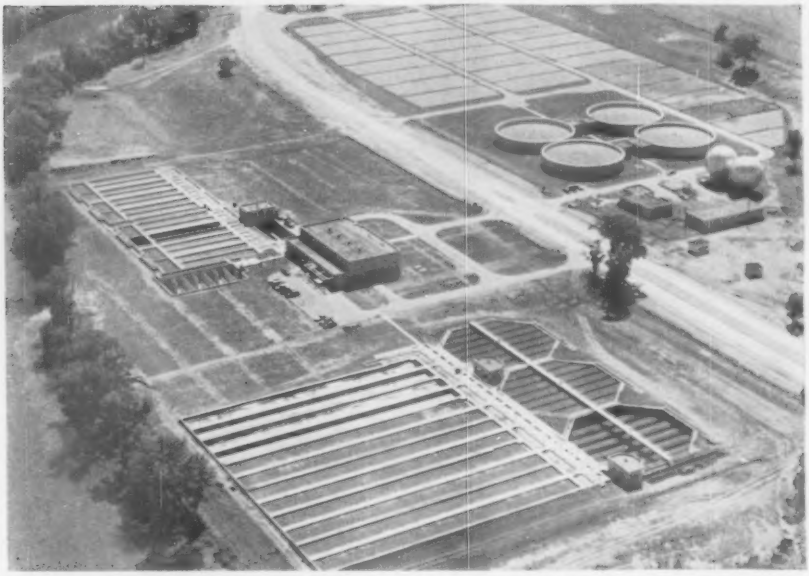

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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

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Contents

Sewage Works

Sludge Filtration and Use of Synthetic Organic Coagulants at Hyperion. By R. D. Bargman, William F. Garber, and Joe Nagano 1079

Modification of the Tracer Measuring Method in Settling Basins. By L. Muszkalay and I. Vágás 1101

Transformation of Some Lipids in Anaerobic Sludge Digestion. By H. Heukelekian and Peter Mueller 1108

An Apparatus for the Continuous Delivery of Small Volumes of Liquid. By G. C. Ware 1121

Industrial Wastes

Effects of Radioactive Materials on Anaerobic Digestion. I. Radiophosphorus. By Werner N. Grune, Donald D. Bartholomew, and Cecil I. Hudson, Jr.... 1123

Activated Citrus Sludge—Vitamin Content and Animal Feed Potential. By Marshall H. Dougherty and Robert R. McNary 1151

Basic Data for Chemical Waste Disposal. By Robert W. Haywood, Jr. 1156

Color Removal in Waste-Water Treatment Plants. By N. L. Nemerow and T. A. Doby 1160

Stream Pollution

A Graphical Solution of the Oxygen-Sag Equation. By T. A. Wastler and N. D. Wastler 1166

Biological Balance in Streams. By Donald C. Scott 1169

An Effect of Biological Imbalance in Streams. By William A. Cawley 1174

The Operator's Corner

Interpreting Laboratory Operating Data. By Robert E. Leaver 1183

Combined Treatment of Poultry and Domestic Wastes. By J. M. Roberts 1186

Interesting Extracts from Operation Reports: Detroit, Mich. 1190

Mechanical Maintenance Program. By R. C. Thayer 1194

Radium—Lost and Found. By Ralph O. Wollan 1197

Tips and Quips 1199

Federation Affairs

Thirty-First Annual Meeting Preview 1201

Reviews and Abstracts 1210

Book Reviews 1212

Proceedings of Member Associations

Montana Sewage and Industrial Wastes Association 364a

New York Sewage and Industrial Wastes Association 366a

New Jersey Sewage and Industrial Wastes Association 368a

Arkansas Water and Sewage Conference 370a

Kansas Sewage and Industrial Wastes Association 370a

California Sewage and Industrial Wastes Association 372a

Virginia Industrial Wastes and Sewage Works Association 374a

Equipment and Supply Lines 378a

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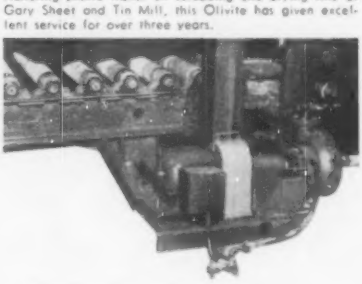

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Sewage Works

SLUDGE FILTRATION AND USE OF SYNTHETIC ORGANIC COAGULANTS AT HYPERION *

By R. D. Bargman, William F. Garber, and Joe Nagano

Respectively, Assistant Chief Engineer, Laboratory Director, and Chief Chemist, Sewage Treatment Division, City of Los Angeles, Calif.

Process variability and high costs of vacuum filtration, necessitated either the improvement of the operation to a point where it would effectively remove the digested sludge produced, or the utilization of some other method at the Los Angeles Hyperion sewage treatment plant. After considerable work it was concluded that the solution to the problem did not lie in improving the mechanical equipment, because such equipment performs well in other industries. Newer filter media and modifications in filter design allowed improved yields; but in the disposal of digested sludge far-reaching process improvement is needed rather than equipment improvement.

As the work progressed it seemed clear that the conditioning or coagulating chemicals offered some promise toward the necessary improvements. Little could be expected from the classical inorganic materials usually used, but work in the field of synthetic polymer coagulants indicated that the required improvement might be possible. If such a material could be developed and sold at reasonable prices, it could become a deciding factor in determining whether vacuum filtration should be continued in plants such as Hyperion. It could also influence thinking concerning solids disposal in plants yet to be designed.

Outline of Problem

The Hyperion plant provides for primary sedimentation followed by "high-rate" activated sludge treatment (1) and secondary sedimentation. Modifications are currently under way (2)(3)(4). The waste activated sludge is returned to the head of the primary sedimentation system and settled with the raw solids. The sludge solids are digested anaerobically (5). Until September 1957, disposal of digested solids was by means of elutriation, vacuum filtration, and heat drying. The fertilizer produced was marketed in the local area.

The current modification program provides for an alternate method of sludge disposal by means of a submerged sludge outfall discharging 7 miles offshore into an underwater canyon. Earlier papers (6)(7)(8) indicated that discharge into deep water at the 7-mile distance would cause no nuisance, pollution, or contamination. Experience since September 1957 indicates that this is substantially correct.

The Hyperion mechanical dewatering plant was placed in operation in September 1950. Except for the usual minor adjustments of a new facility, the equipment has functioned well and has exhibited no inherent defects.

* Presented at 30th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Boston, Mass.; Oct. 7–10, 1957.

However, as already noted, great difficulty has been experienced in dewatering the sludge solids and at no time has production approached the quanity of solids theoretically available.

When operation first started, an improvised elutriation procedure was utilized; therefore, the resulting poor yields were not thought unusual. However, activation of permanent and well-designed elutriation facilities led to little production improvement and it became apparent that the poor filtration resulted from the characteristics of the sludge itself. There was thus little hope that the entire digested sludge production could be filtered or that operational costs could be kept anywhere near a point where fertilizer sales would cover a reasonable portion of the production cost.

This had not been readily apparent from the literature during the design period, but investigation after production was started showed that sewage sludge ranked low as a filterable material and extremely low in value in the materials normally handled on rotary vacuum filters. As the picture developed at Hyperion, it became increasingly clear that radical improvements in the vacuum filtration process would have to be found or another method of disposal would be necessary. In fact, operation over the first seven years was in effect an alternate method of disposal for almost 50 per cent of the solids; namely, overflow of the elutriation wash water to the ocean.

This paper, therefore, outlines experimental work performed on Hyperion sludge solids using various coagulants and different methods of sludge conditioning. In addition, data obtained during the present 2½-yr period of operational use of one of the synthetic polymer coagulants are summarized. To interpret these data and to place them in their proper perspective, they are examined in view of the present experience of the cities in the Pacific States with the vacuum filtration of sewage sludge.

Discussion of General Problem

Sludge Characteristics

Using the criteria of other industries, filtration rates obtainable with sewage sludges are not sufficient to establish this as a usable process. As indicated in Table I, sewage sludges rank extremely low in the scale of filterable materials, being in fact close to an unfilterable designation. In addition, they rank very low in product value.

It should be emphasized that Table I does not include the factor of preparation cost. Thus, sewage sludges require expensive coagulants, whereas cement slurry, the only material close to sludge in market value, requires only grinding. By comparing production cost versus market value, the picture regarding sewage sludges would be even poorer.

Table I shows little correlation between organic-inorganic content and filter rate. Sugar cane muds are a mixture of coarse cane fiber, lime, and saccharate. They have a large percentage of organic material, but the filtration rate is governed by the size and amount of coarse fiber. Salt is entirely inorganic and filters well, whereas cement slurry, also inorganic, filters quite poorly. The reason is ap-

TABLE I.—Materials Normally Concentrated on Rotary Vacuum Filters*

Material	Filter Rate (psf/hr)	Estimated Market Value Produced From Raw Products ($/sq ft/hr)
Sugar cane muds	400–800	1.70–3.40
Salt and crystals	300–500	3.00–5.00
Sugar, carbonation mud	110	1.20
Cyanide slimes (gold and silver)	20–85	1.25–50 (min)
Flotation concentrates	13–60	0.50–3.50
Paper pulp	8–50	0.40–2.50
Cement slurry	2–40	0.03–0.55
Pigment (lithopone)	8–16	0.68–1.36
Sugar (saccharate, Steffens)	8	0.50
Sewage sludge	1–10	0.002–0.10

* Data from *Chemical Engineers' Handbook*, Perry, Third Edition (1950).

parently particle size and shape. Crystals form a porous surface and mat, but the very fine cement slurry forms a thin relatively impervious mat. Paper pulp is almost entirely organic and has a rate varying from poor to good, depending on the length and fineness of the pulp. Cyanide slimes and flotation concentrates are inorganic, but possess filtration rates about the same as that of paper pulp. Particle size and compressibility seem to be the key in the filtration rate on these materials. Sewage sludge varies from 40 to 80 per cent in organic content, and the 80 per cent material is as likely to filter well as the 40 per cent material.

In summary, the organic content, as such, is not as important to filtration and filter rates as are characteristics of particle size and shape. At Hyperion this has been amply shown by the fact that after prolonged elutriation the fine materials are washed from the sludge, leaving a large amount of straw or chaff-like material. Such material has the same percentage of organic materials as the regular elutriated sludge, but gives 30 per cent greater yields at only 80 per cent of the coagulant demands.

The importance of the size and physical characteristics of the particles to the filter rate is not a new concept. At outlined by Carman (9), Ruth (10), and Walker *et al.* (11), Poiseuille's equation is generally considered to be basic for cake filtration. In this equation the compressibility of the material being filtered is the controlling factor, and the reason for difference in rates rests with the differences between crystalline and amorphous shapes.

Particle size enters into the equation in that very small particles lead to compressible cakes and consequently to high cake resistance to the passage of filtrate. In sewage sludge, coagulants increase particle size, decreasing compressibility and thus converting a basically unfilterable material to one which can be handled. Filtration theory is beyond the scope of this paper, other than to point out that the behavior of sewage sludge can be predicted from present theory (12) (13) (14).

Elutriation Experiences

Certain processes associated with vacuum filtration are necessary to the process, but introduce problems of a different type. Thus, at Hyperion it was found that elutriation is absolutely necessary prior to filtration of digested sludge. Without elutriation, and using currently accepted coagulants, coagulant costs would be of the order of $20 per ton, whereas they are of the order of $4 per ton with elutriation. The reasons for this are covered in the fundamental work reported by Genter (15). However, at Hyperion elutriation had acted to transfer a problem from the filter drums to the aeration tanks, and it is probable that secondary treatment could not have been continued even with a very large investment in more aeration tanks and air compression capacity had elutriation overflow not been discharged directly to the ocean.

Elutriation is not a complete process, but it partially solves one problem by shifting that problem to another point in the treatment process where it must be handled in another way. Other operators have recently reported similar observations (16) (17) (18). The action of the elutriation system in fractionating and settling the coarser particles while leaving the fines unrecovered is illustrated in Table II.

During the last full year of filter operation at Hyperion the plant handled 256 mgd, resulting in a total of 387 tons per day of raw solids. Of these, 72 tons were disposed of at sea as secondary effluent and digestion accounted for 315 tons; of the latter, gas totaled 155 tons, and 160 tons were elutriated. From the elutriation tank,

TABLE II.—Operation of Hyperion Elutriation System

	1954–55	1955–56	1956–57
Total digested solids available for elutriation (tons/day)	158	158	160
Total digested solids removed as underflow from elutriation tank (tons/day)	78	78	92
Total digested solids escaping as overflow* from elutriation (tons/day)	80	80	68

* To sea after digestion.

92 tons were filtered and dried and 68 tons overflowed to sea. This compares with the design factors of 245 mgd, 347 tons of raw solids, 295 tons to digestion (including 112 tons of gas and 183 tons of digested sludge to elutriation; filtered, and dried), and 52 tons to sea as secondary effluent.

Of the 160 tons per day of digested sludge actually elutriated, only 92 tons per day were recovered as fertilizer; therefore, more than 40 per cent was lost to the ocean in the overflow. The treatment efficiency would appear to be only 64 per cent, because 36 per cent of the incoming solids reached the ocean. It must be cautioned, however, that more than 50 per cent of the 36 per cent loss represents digested material that had been through the treatment processes, thus contributing much less of a pollution or nuisance problem than would an equivalent amount of raw solids. This reduction in load can be estimated from the work by Rawn and Candell (19), which would suggest between 80 and 90 per cent. In actuality, the treatment processes, as such, removed more than 80 per cent of the solids.

Dilution with Effluent

A basic deficiency in the sludge disposal process required that a certain amount of the digested solids be recombined with the secondary effluent for disposal. In any case, these digested solids represent an operational load which poses problems of resulting trash on the beaches, as well as an estimated additional chlorine cost of $150 per day for coliform control.

Recirculation

Recycling the elutriation overflow through the plant placed such a load on the aeration facilities that operation of the entire secondary treatment process was placed in jeopardy. This aspect is covered in a previous paper (1). In short, however, a considerable trial was conducted of the recycling of the overflow back through the primary sedimentation system to the aeration system, and there simply was not enough air to handle the extra load. A great deal more aerator and compressor capacity might have enabled the system to operate in the aerobic zone, but the recycling and gradual build-up of solids would have forced an inevitable collapse of the system.

Coagulant Experiences

Filtration of the additional solids was equally impracticable to consider. Figure 1 shows the relation between the rate of filter yield and the operations level, by monthly average, at Hyperion over the last five years of operation. The filtration rate declined as the percentage of sludge filtered increased. This is logical, and arises from the characteristics of the sludge and of the filtration and elutriation processes. The relationships shown in Figure 1 are of the greatest importance to a facility engaged in or entering into sludge filtration.

Sewage sludge is a suspension of mineral and organic particles in an aqueous medium. It is well known that such a suspension increases in stability as the fineness of the particles increase and that when fine enough a very stable colloid suspension is achieved. In addition, it is recog-

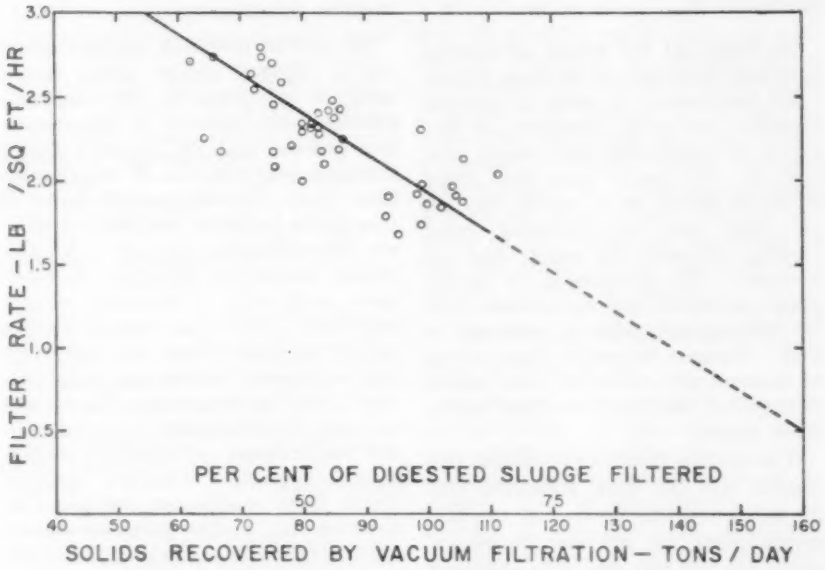

FIGURE 1.—Relation between filter rate and operation level.

nized in a number of fields that the more stable a suspension is, the more coagulant is required to break and precipitate it. Thus, in mineral sols the gold number is used to define coagulating properties and in asphalt emulsions the amount of calcium chloride necessary for precipitation is used as a standard. It should therefore follow that the finer and more stable a sludge suspension, the more coagulant is needed to clump and precipitate it. In addition, as outlined earlier, the finer and more amorphous the particles are in a filter cake, the more compressible will be the cake, and the more difficult to filter. Thus, a finely ground suspension is not only difficult to filter but requires more coagulant. This is felt to be generally true of sewage sludges and the experiences at Hyperion have generally confirmed it.

Filter Rates

Figure 1 is thus more explainable. A selective fractionation of the sludge solids occurs in the elutriation tanks and as more of the sludge production is handled more of the finer materials are retained. As more and more of the production is removed from the bottom of the elutriation system, the greater the relative fineness becomes and the harder the filtration step is. This, of course, assumes that the alkalinity and other products of digestion which interact with the coagulant are washed out.

In Figure 1, then, the dotted line illustrates one possible projection of the curve as the percentage of sludge filtered increases. Experience at Hyperion indicates that the curves would dip toward a zero filter rate as the sludge percentage approached 100. In any event, there was no indication that the rate would be greater than indicated by the dotted projection, so it represents a conservative estimate for discussion purposes. It will be noted that a minimum rate of 0.5 psf/hr is estimated as the sludge percentage recovered reaches 100.

Estimated Equipment Needs

In Table III the actual production data and projected yields from Figure 1 are interpreted in terms of vacuum filtration equipment necessary at Hyperion to handle the total sludge production. It can be seen that about 50 filters would be necessary for 100 per cent recovery, assuming some standby capacity for repair and recovering. The investment in capital plant, personnel, and operational costs for 100 per cent recovery obviously is high. Because the solids that cannot be economically recovered also cannot be recycled, they must be handled by other means.

It is obvious from the preceding discussion and the data presented that the solids removal portion of the Hyperion plant has not met design expectations. It also should be apparent that complete in-plant recovery of the solids would require a considerable increase in plant size and subsequent increase in operation and maintenance cost. It must be emphasized, however, that the equipment is not at fault. The equipment operates up to its inherent design potential. Rather, the process limitations of dewatering a very fine suspension of compressible solids has led to the inability to meet design rates of solids recovery.

TABLE III.—Vacuum Filters Required to Recover Various Amounts of Solids

Available Dig. Sol. Filtered (%)	Solids Removed (tons/day)	Filter Rate (psf/hr)	Filter Surface Required (sq ft)	Filters Required*
37	60	2.85	1,750	4
50	80	2.37	2,810	5
63	100	1.90	4,400	8
69†	110	1.66	5,550	10
75‡	120	1.43	7,000	13
87‡	140	0.95	12,300	22
100‡	160	0.50	26,600	47

* At 570 sq ft each.
† Highest production to date.
‡ Projected from data.

Possible Solutions

To provide complete in-plant recovery of digested sludge solids, means must be provided to (a) eliminate process losses inherent in the elutriation process, and (b) improve sludge filtration performance. It is apparent that great benefits would occur if coagulants could be developed to obviate the elutriation process. As previously stated, the filtration improvement needs to be of the order of several fold. Given the sewage sludges usually handled, it does not seem likely that equipment refinements could produce such improvement. There will be some improvements in design; but the basic theory of filtration argues against greatly increased product yields from equipment changes. If, however, the sludge particles can be made larger and the cake significantly less compressible, great filtration rate improvements can result. There is little hope that the classic inorganic coagulants can develop a 10-fold cost-yield improvement; but the synthetic polymer materials now available or in development offer some promise of this.

Cost Data

In delineating the problem of solids disposal, some discussion of costs is inevitable. The operation costs for processing sludge at Hyperion during the fiscal year 1956–57, the last year of full-scale operation of the mechanical dewatering plant, are given in Table IV, together with the estimated costs of operation assuming an ideal coagulant capable of filtering all sludge without elutriation and at a coagulant cost of $2 per ton of dry solids processed. No such coagulant exists at present; but if a material capable of coagulating unelutriated digested sludge to a degree which allowed almost 100 per cent recovery could be developed and sold at that price, filtration could compete with other disposal processes now available.

TABLE IV.—Costs of Fertilizer Production

Item	Actual, Fiscal Year 1956–7	Estimated with Ideal Filtration
Production of digested sludge (tons/day)	160	160
Dig. sludge removed in mechanical dewatering plant (tons/day)	92	160
Cost of solids removed in mechanical dewatering plant ($/ton)*:		
Elutriation	1.15	None
Filtration	6.35	3.50
Drying†	4.02	3.50
Fertilizer handling	2.70	2.50
Cost of solids disposed of as overflow from elutriation system ($/ton)‡	1.63	None
Income from fertilizer sold ($/ton)	4.00	6.00§
Net cost of solids removed in mechanical dewatering plant ($/ton)	11.85	3.50

* Does not include administrative overhead.
† Does not include gas fuel charge.
‡ Principally disinfection at $150 per day and computed on solids filtered.
§ Increase in value due to recovery of nitrogen not lost in fines and elutriation.

It is assumed that the fertilizer produced by such a coagulant would be richer in nitrogen and thus more valuable, because the loss of the high nitrogen content fines would be eliminated. Table IV covers operation costs only and does not reflect the sizeable capital investment required for filtration equipment.

It must be remembered that the actual data represent a capture of only 60 per cent of the solids. If all were captured under present conditions, it is obvious from Table III that both capital and operating costs would rise substantially. Without major improvement the process appears unattractive. If filtration could be improved as outlined in the second column of Table IV, and all sludge recovered at this rate, costs would be in line with alternate schemes of disposal.

As a corollary of cost, the conservation of valuable assets must be considered. Recovery of fertilizer is of course desirable, but true conservation does not mean expenditure of chemicals, fuel, equipment, and manpower to produce a material worth less than that expenditure. Disposal of sludge is a public necessity and the best interest of all, including conservationists, are served when the most economical solution is utilized.

Procedures of Investigation

Tests on Equipment

At first it was not clear that the characteristics of the sludge itself were chiefly responsible for the poor filtration. The equipment presents an obvious area of investigation, so a number of changes were instituted. Various filter drum speeds were used, blankets or filter surfaces of many types were utilized, several bridge settings in the vacuum valves were tried, filtration surface washing was thoroughly investigated, and several cake removal systems were studied. Many changes which aided equipment operation were made.

The changes, however, aided in only a minimum degree and performance remained below the anticipated level. The bid specifications had stated that the filters as installed should produce 5 psf/hr. The manufacturer agreed to this and was as puzzled as plant researchers by the fact that levels of 2 to 2.5 psf/hr were all that could be obtained at $FeCl_3$ dosages of as high as 12 per cent by dry weight. By using 4 per cent $FeCl_3$ and 16 per cent CaO, the 5-psf/hr yield was reached for a short test period, but a two-month plant-scale operation failed to confirm this figure. In short, equipment manipulations and modifications did not solve the problem.

Filtration Test Apparatus

As it became clear that the equipment as such was capable of perform-

ing to its inherent capacity but that the sludge for some reason was difficult to filter, the work spread into many areas. Production filters were used for some experiments, but this was found to be expensive and interfered with the need to use all available equipment to process the daily solids production. Much of the testing was then done on Büchner funnels, 0.1-sq ft filter leaves, or 1- by 1-ft model rotary vacuum filters.

The Büchner funnel was the least satisfactory method, in that its data could not be used to give a good estimate of production to be expected on a prototype filter. It gave a qualitative idea of filterability, but little quantitative information.

The 0.1-sq ft filter leaf gave information of some quantitative value if the correct procedures were closely followed (20)(21). With the formation of poor-filtering, compressible cakes, a close relationship between the filter leaf and the production filters existed. As the filtration characteristics improved the filter leaf became less reliable.

The 1- by 1-ft model rotary vacuum filter was sufficiently similar in operation to the large prototypes that quantitative estimations could be made. Figure 2 shows the relationship between the filter leaf, the 1- by 1-ft model, and the production filter on Hyperion elutriated digested sludge using $FeCl_3$ and a synthetic organic polymer coagulant.

The divergence of the filter leaf data from that of the 1- by 1-ft model and the prototype filter with increased $FeCl_3$ dosages and improved filterability is apparent. However, as shown by Figure 2, adequate data are available to enable the prediction of plant-scale operations when new processes are considered.

Effect of Particle Size

Study of the literature during the design period and questioning of vari-

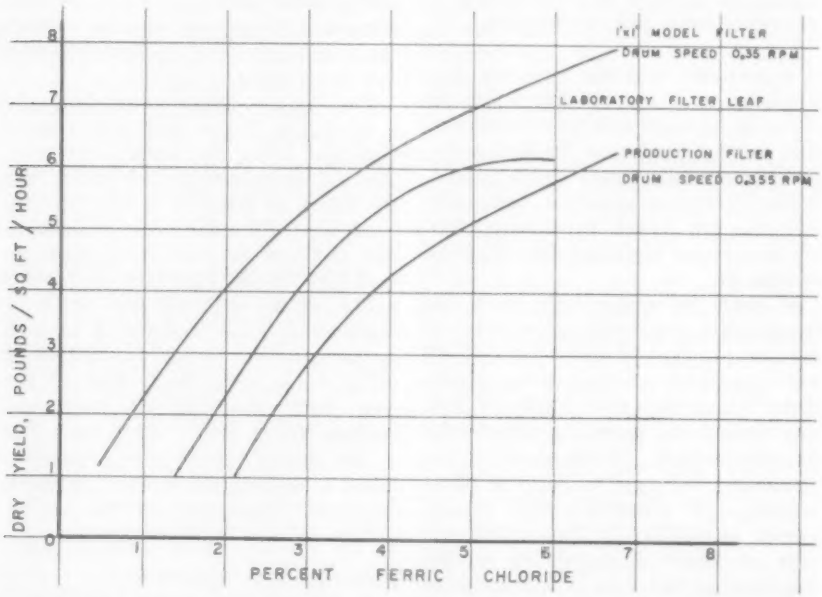

FIGURE 2.—Comparison of yields of laboratory filter leaf, 1- by 1-ft model filter, and production filter (0.035 per cent Separan used).

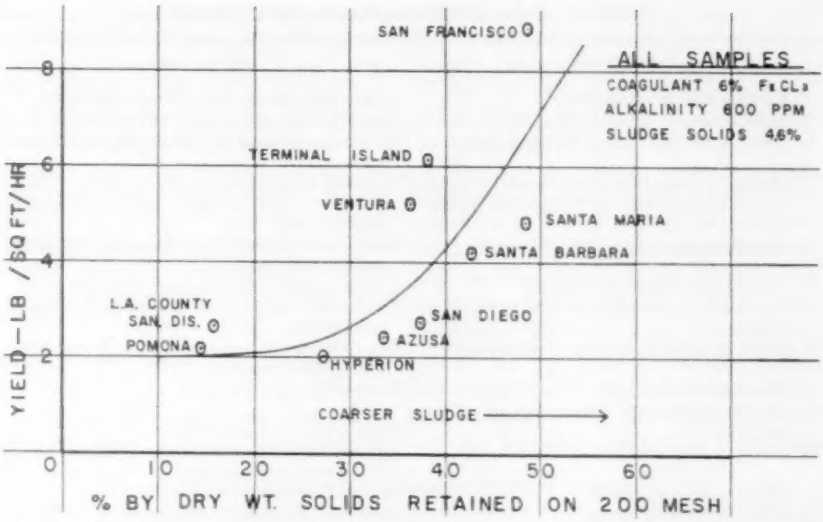

FIGURE 3.—Relation between filter yield and particle size for elutriated digested sludge in California (0.1-sq ft filter leaf tests).

ous agencies throughout the country had led to the belief that yields of 4 psf/hr at 3 per cent $FeCl_3$ would be easily obtainable. As it became apparent that this would not be the case at Hyperion, due to unusual sludge characteristics, the question of just what these characteristics might be was the next problem.

In this phase, industrial wastes, sludge protein content, grease, detergents, and several other items were investigated, but nothing very unusual was found. Filter rates were ascertained on sludges from all over California and attempts were made to determine how they were similar to or different from the Hyperion digested sludge.

It became obvious that the only difference measurable by the techniques being used was the size of the particles. In addition to the filter rate, each of the sludges was analyzed for the amount of material passing a 200-mesh (0.0029-in.) standard screen.

Figure 3 shows that in general the coarser the sludge the better the filtration rate. There were some variations arising from other sludge characteristics which affect cake compressibility. For example, Terminal Island sludge had a large amount of fish scales arising from canning operations. These tended to produce a fast-draining cake. However, the single characteristic of particle size can explain in large part the differences noted in filtration characteristics.

As outlined earlier, these findings are in line with filtration theory, because particle size is one of the principal controlling factors in cake compressibility. It should also be noted that the best filtering sludge found was within the limits noted in Table I and thus is subject to the same economic considerations.

Experimental Attempts to Improve Filtration

In the attempt to change the sludge filtration characteristics so as to improve filtration experience, a wide range of tests was tried. Table V lists these tests and briefly summarizes the observations made. A great deal of quantitative data is available on

TABLE V.—Range of Filtration Experiments at Hyperion

Experiment	Observations
1. Particle size vs. filterability	Larger particle size gives better filterability
2. Sedimentation rates vs. filterability	Better sedimentation rate; better filterability
3. Effect of stirring and pumping sludge	Solids comminuted; filterability degraded somewhat
4. Change in coagulant effectiveness by reduction of ferric to ferrous by digested sludge	Digested sludge reduced 25 to 35% of ferric chloride to ferrous salt; reduced coagulant effectiveness
5. Raw primary sludge filtration	Poor, but better than digested elutriated; particle size larger
6. Unelutriated digested filtration	Almost unfilterable; too many fine particles
7. Raw primary plus elutriated digested filterability	Filterability varies according to percentage of components
8. Effect of different degrees of elutriation	More elutriation gives less fines, better filterability, less nitrogen
9. Interstage elutriation	Little effect on filterability
10. Process equipment manipulations, filters and digesters	Little effect on filterability
11. Effect of detergents	Amounts now found, little effect; large amounts (1%), serious degration
12. Effect of heating sludge	Improved filtration; uneconomic
13. Effect of freezing sludge	Improved filtration; uneconomic
14. Effect of grease removal	Improved filtration; uneconomic
15. Use of admixtures	Yield increased by weight of admixture
16. Use of precoats	Some benefit, but expensive
17. Effect of various types of filter cloths	Some improvement in filterability and operation costs
18. Formaldehyde treatment of sludge	No noticeable benefit
19. Phosphoric acid and lime treatment of sludge	No noticeable benefit
20. pH control	No noticeable benefit by changing present pH
21. Solids concentration:	
Elutriated digested	Moderate improvement
Unelutriated digested	Still very poor filterability
22. Addition of chlorine:	
Between elutriation stages	Some help to filterability; expensive
After elutriation	Some help to filterability; expensive
23. Digestion studies:	
Thermophilic	Aided filterability; low nitrogen
Mesophilic	Poor filterability; acceptable nitrogen
Gas production vs. filterability	Little noticeable correlation
Digestion of volatiles vs. filterability	Some possible correlation
24. Variations in filters:	
Rate of mixing in filter pan	Best filterability with minimum mixing
Rate of drum rotation	Filtration rate increase with drum speed; however, equipment limited benefits
Various filter backing materials	Change to hard rubber helped maintenance
Various cake removal devices	No particular advantage
Various bridge settings	No particular advantage
25. Use of bark wool to increase size	Not effective
26. Use of expanded vermiculite and other expanded silica products as aids	Not effective

each test, but for the purposes of this paper the outline of Table V is felt to be adequate.

It will be noted from Table V that there was little effect in manipulations involving physical items, such as cloths, filter aids, and machinery. Changes which produced the greatest effect were also quite expensive, and the improvements were in general too small to justify adoption. Changes in digestion helped, but produced a low

nitrogen product having limited sales potential (5). There was the possibility of interference from materials like detergents, but the quantities had to be quite large to be felt. Interstage elutriation gave little benefit at this site and chlorination during elutriation could not oxidize enough of the reduced ferric ion to pay for its cost. Other points are obvious from Table V and others not outlined were tried, but the major work along these lines is shown.

Experiments with Coagulating Materials

Because the coagulants seemed to offer the best hope of salvaging the filtration process at Hyperion, a great deal of laboratory and plant time was spent in testing coagulating materials. Table VI lists most of the products tried, with a brief note of observations as to their effectiveness.

Worthy of note is one plant-scale operation undertaken. Experience elsewhere with the use of lime, coupled with the need to increase production, led to operation of the filter plant with lime and ferric chloride for two months. However, the average increase in yield was only slightly larger than the weight of lime added. This fact, together with the alkaline nature of the fertilizer produced, made the

TABLE VI.—Types of Coagulants Tested at Hyperion

Coagulant	Observations
1. Ferric chloride	Now in use; best inorganic material available
2. Ferric chloride + potassium dichromate	Expensive; possibly somewhat better than $FeCl_3$
3. Ferric chloride + aluminum sulfate	Poorer than $FeCl_3$ alone
4. Aluminum sulfate (filter alum)	Unfilterable
5. Ammonium alum	Unfilterable
6. Sodium aluminate	Unfilterable
7. Aluminum chlorohydrate	Unavailable; equivalent to or better than $FeCl_3$
8. Ferric sulfate	Poorer than $FeCl_3$; not competitive in price or effectiveness
9. Calcium chloride + OH^-	No benefit
10. Dresinate TX (Hercules)	No benefit
11. Dresinate XX (Hercules)	No benefit
12. Carboxymethylcellulose (Hercules) (several variations)	No benefit
13. Nopco 2125	No benefit
14. Guartec (General Mills)	No benefit
15. Lustrex X-886 (Monsanto)	Good coagulant; poor filtration
16. Lustrex X-889 (Monsanto)	Good coagulant; aided filtration; unstable
17. Bylig	No benefit
18. Orzan SL45	No benefit
19. Orzan L50	No benefit
20. Activated carbon	No benefit
21. Ammonium lignin sulfonate	No benefit
22. Agrilon N (American Polymer)	Good coagulant; aided filtration
23. Cyanamid 101, 201, 301	Good coagulant; poor filtration
24. Carbide polymers (19 samples)	Good coagulant; poor filtration
25. Tretolite coagulants (20 samples)	No benefit
26. Nalco (5 samples)	No benefit
27. Nalco 600	Good coagulant; aided filtration
28. Cyanamid Aerofloc 548, 552, 3000, S-3100	Good coagulants; some aid in filtration
29. Cyanamid Aerofloc S-3019	Good coagulant; aided filtration
30. Du Pont EXR 102A	Good coagulant; aided filtration
31. Lacco polymer coagulant	Good coagulant; aided filtration
32. Hagan Nos. 7, 11, 15, 18	Good coagulants; aided filtration
33. Separan 2610 (Dow)	Good coagulant; aided filtration; now in production use

usage of lime-ferric chloride impractical at Hyperion.

In general, the Hyperion work was with elutriated digested sludge, although some tests were made with raw primary, raw activated, and unelutriated digestion materials. As will be noted in Table VI, the inorganic materials offered little hope of major improvement, whereas several of the new synthetic materials aided the process substantially. Many of the polymers tested did an outstanding job of coagulating the sludge solids, but the flocculated material so obtained was not compressible; therefore, dewatering by vacuum filtration was practically impossible. However, other polymers changed the solids characteristics enough to aid filtration.

Most of the synthetic polymer coagulants required the concurrent use of an inorganic coagulant such as $FeCl_3$, although some were found that acted at very small concentrations and needed no accompanying coagulant. It should be noted that only two of the synthetics were effective with either the raw sludges or with unelutriated digested sludge, and only two were effective without the concurrent use of inorganic coagulants.

A synthetic coagulant that would answer all of the problems of a sludge filtering operation has not yet come to the authors' attention; but materials have been observed with characteristics that could promise much for the future. A polymer formulation which is active with raw, unelutriated digested, and elutriated digested sludges and does not need an inorganic coagulant with it has been tested. It is effective in very low concentrations on elutriated digested sludge and much less effective on unelutriated and raw sludges. However, the fact that a material has been found which coagulates all of the common types of sludges in some degree is encouraging, because the types and numbers of polymers is virtually limitless and as research broadens, coagulants allowing the necessary improvement in the process become more possible. It must be pointed out, however, that little coagulant research is aimed at sewage sludge filtration because the major market for such materials lies in areas such as treatment of mineral slimes, recovery of coal fines, and removal of particulate solids from waste flows. It is a fortuitous accident that these synthetic coagulants are useful in the sludge filtration field and one of the jobs of the industry is to interest the coagulant producers in this specific problem.

Tests and Production Runs with a Commercial Synthetic Coagulant

Table VI shows that a number of the synthetic polymer coagulants tested were effective in improving filtration yields. One of the first to be available on a commercial basis in a stable, storable form was Separan 2610.* This was described as a high molecular weight polyacrylamide and was supposed to be effective over a wide pH range, and thus insensitive to most variations in sludge condition. It was supplied as a dry powder in 50-lb sacks and showed no loss of effectiveness in storage as long as the material was kept dry. A well-planned device for preparing dosing solutions was available and the solutions so prepared were stable for a week but less than a month. It was a reasonably effective coagulant for elutriated digested sewage sludge, so a plant-scale test seemed warranted. Information from plant-scale tests led to the adoption of Separan for production use, and it has now been utilized for more than 2½ years at Hyperion. There are other commercially competitive materials, which have about the same price structure and effectiveness on elutriated digested sludge, but experience in handling the present material is such that no change is contemplated

* Dow Chemical Co., Midland, Mich.

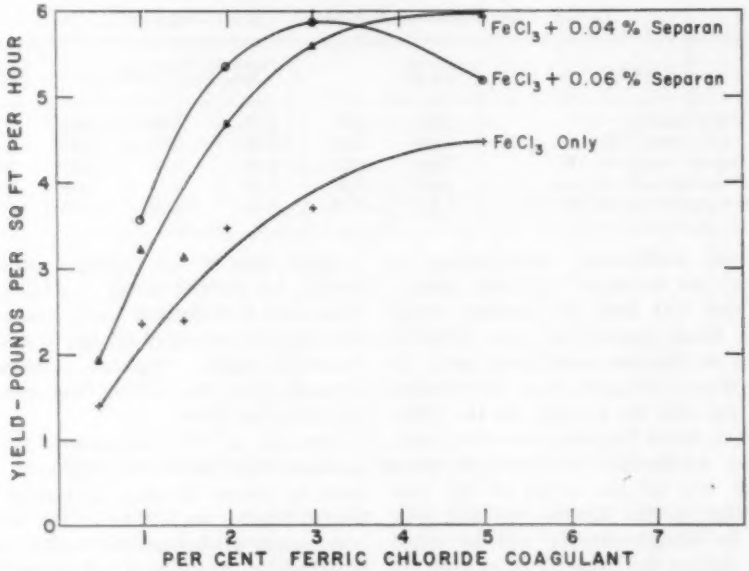

FIGURE 4.—Laboratory filter leaf test on effect of organic coagulant dosage.

unless a material bettering it on a process and/or cost basis can be found.

Figure 4 summarizes the laboratory tests which led to the trial of Separan 2610 on the production filters. It will be noted that when 0.04 or 0.06 per cent of Separan was added with $FeCl_3$ dosages of from 2 to 5 per cent on a dry solids basis, yield increases of the order of 2 psf/hr, or of about 45 per cent, were obtained. Analyzing horizontally, this also means that 0.04 per cent Separan and 2 per cent $FeCl_3$ gave the same yield as 4 per cent $FeCl_3$ alone. It is also apparent that at the 0.06 per cent Separan dosage, deflocculation occurred as the $FeCl_3$ was increased. This was also true of the 0.04 per cent rate as the $FeCl_3$ was increased beyond the values plotted in Figure 4. However, the general test results indicated that a plant-scale test of the material would be justified.

During this period the average performance of the production filters was such that a $FeCl_3$ dosage of 3.9 per cent was necessary. With this dosage, coagulant costs were $3.67 per ton of dry fertilizer produced. As stated, the test had suggested that this cost might be reduced and that other costs arising from maintenance occasioned by excessive $FeCl_3$ might be cut. It was concluded, however, that the production filter experiment should provide that total coagulant costs be no higher than those currently prevailing if the procedure was to be justified.

On the basis of Figure 4, it was reasoned that 0.06 per cent should represent the maximum Separan dosage, because deflocculation apparently became a problem as this dosage was exceeded. At the $FeCl_3$ and Separan prices then prevailing, it was concluded that 2.9 per cent $FeCl_3$ and 0.06 per cent Separan would represent the maximum economic dosage. With this in mind, a several week production test was made using 2.9 per cent $FeCl_3$ and, respectively, 0.03, 0.04, 0.05, and 0.06 per cent Separan. The production test was not as clear-cut as the laboratory filter leaf tests, but

TABLE VII.—Evaluation of Synthetic Organic Coagulant

Item	Average, 1954–55	Production Test, Filter Plant				Average, 1955–56
Yield (psf/hr)	2.20	2.72	2.77	2.69	2.62	2.23
$FeCl_3$ dosage (%)	3.90	2.90	2.90	2.90	2.90	2.16
Organic coagulant (%)	None	0.03	0.04	0.05	0.06	0.03
Coagulant cost ($/ton)	3.67	3.35	3.56	3.77	3.98	2.66
Coagulant cost saving (%)	0	8.70	3.00	−2.70	−8.50	27.50

it was sufficiently encouraging to justify an extended full-time trial.

Table VII lists the average conditions found during the year 1954–55, when no Separan was being used. It also shows the data from the production test and the average for the 1955–56 year, when Separan was being used. Filter production in both of these years was of the order of 80 tons per day, so the figures for each year can be compared. It will be noted that during the 1954–55 fiscal year 3.9 per cent $FeCl_3$ was used to obtain a 2.2-psf/hr yield at a coagulant cost of $3.67 per ton. The plant-scale test of Separan showed an improvement in yield to about 2.7 psf/hr, but the cost saving per ton was a moderate 8 to 9 per cent. The best Separan dosage seemed to be at 0.03 per cent, so it was decided to operate at this level and to add $FeCl_3$ such that the yield would be about the same as it had previously been. Operation considerations made it desirable to aim at the usual production level rather than to increase the unit rate.

Table VII shows that the production rate for 1955–56 was the same as that for 1954–55, but that 2.16 per cent $FeCl_3$ and 0.03 per cent Separan were used instead of the previous 3.90 per cent $FeCl_3$. Coagulant cost dropped from $3.67 per ton to $2.66, for a 27.5 per cent decrease.

Separan is only effective on elutriated digested sludge, leaving the problem of the elutriation overflow previously mentioned. Ability to coagulate unelutriated digested sludge would eliminate the solids loss in elutriation and upgrade the fertilizer, because less of the nitrogen content would be washed away. Ability to coagulate raw sludges would place the filtration of activated sludge in a more favorable light. Separan is thus of limited value in solving the general filtration problem.

Because of the immediate benefit commercially available polymers can give to plants filtering elutriated digested sludge, an outline of the actual mechanics of operation would seem worthwhile. Figure 5 is a diagrammatic illustration of the Hyperion installation using Separan. The dry material is dissolved by mixing it with water in the venturi throat of an aspirator and then by agitation with a propeller mixer. Contact of all dry particles with water must occur at the same time in the venturi throat system or the material becomes difficult to mix. The solution is quite viscous, so a 0.62 per cent stock solution of the polymer is used As noted, the solution so prepared is subject to degradation; therefore, no more than a week's supply is prepared at any one time.

Inasmuch as quick and thorough contact of the polymer with the sludge particles is essential, the coagulant solution is added by a proportioning pump to the elutriated sludge line just ahead of the centrifugal pump feeding sludge to the regular coagulant mixer. The Separan and sludge have a 2- to 5-min contact period in the piping before the $FeCl_3$ is added in the regular coagulant mixer. Continued mixing after the $FeCl_3$ is dispersed through the sludge containing the polymer tends to degrade the floc,

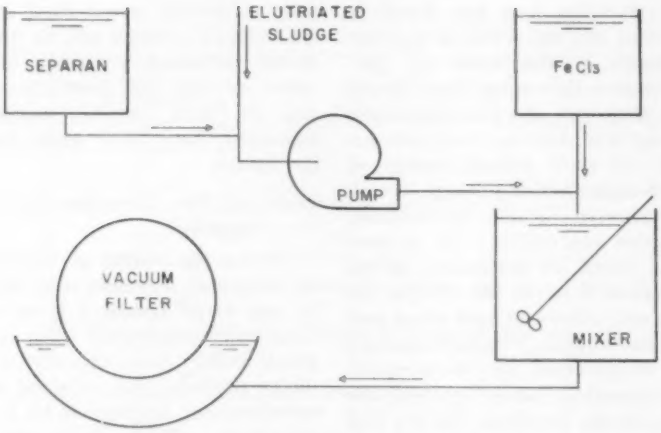

FIGURE 5.—Flow diagram of sludge conditioning and drying system.

making it necessary to determine the allowable amount of mixing.

The polymer and its solution are noncorrosive; therefore, ordinary construction materials can be used for the dosing equipment. As Figure 5 shows, this equipment is quite simple and can be added to most systems with little difficulty. At Hyperion the total cost of materials necessary for the conversion to polymer usage was less than $2,000 and no major design change was required.

The sequence of addition of these materials has been found to be critical. With Separan and sludge, the polymer must be added first and thoroughly mixed before the inorganic coagulant is added. The time for adequate dispersion of the synthetic in each particular installation also must be known if successful use is to be realized. Production use of Separan with $Al_2(SO_4)_3$ for the flocculation of up to 10 mgd of raw sewage at the Valley Settling Basin of the City of Los Angeles, a chemical treatment plant, revealed that the polymer was most effective if added after the inorganic coagulant. Thus, each product must be tested to see whether it should be added before, with, or after the accompanying inorganic coagulant.

Flocculation Theory with Commercial Organic Polymers Tested

The surfaces of particles in a solution are known to take on an electric charge, relative to the solution, which is governed by the pH of the solution and by the composition and structure of the surface of the particles (22) (23) (24). If the particles are small enough the repellent forces of the charge will give a permanent colloidal suspension. Larger particles will slowly settle, but will deviate from Stoke's Law by the effect of the charges upon each other.

It is considered that the particles develop their charge by adsorbing hydroxyl ions from the solution onto the surface of the particle. The number of hydroxyl ions adsorbed is dependent on the nature of the material. The adsorbed hydroxyl ions then attract cations, which form a cloud around the particle for some distance into the solution. The attracted cations are subject to ion exchange; therefore, the Fe^{+++} and Al^{+++} cations produced from the usual inorganic coagulants like $FeCl_3$ and $Al_2(SO_4)_3$ exchange with the Na^+, Ca^{++} and other mono- and divalent ions around the particles.

These trivalent ions are fewer in number and are attracted to the surface strongly, so that when two particles approach they come more closely together than was the case before the monovalent and divalent ions were exchanged. If their normal energy of motion is such that the charge acting over the shorter distance is overcome, the particles can collide. If, on contact, the forces of attraction exceed the dispersive force of the charge, the particles will adhere to each other and flocculation occurs. The rate of flocculation is governed by the strength of the attractive forces between the particles, by the repelling charge, and a number of other factors.

Once flocculation has actually started, as outlined in the foregoing general description, the rate of growth of the floc particles is controlled to a large degree by substances that increase the bond between particles. In iron or aluminum salt flocculation, the hydroxide sols that form constitute chains or bridges which are adsorbed into the flocculated particles, where they act to bind several together into larger, stronger particles which settle more rapidly (25).

The commercially available polymers investigated at Hyperion act in the same manner as the hydroxide sols, except that they are much more effective because of their long chain lengths and many active points. They bridge between several floc particles at once, giving a large, dense, and very tough floc.

These polymers, however, are usually either nonionic or slightly anionic, so they do not enter into the basic ion exchange-flocculation reaction. They are bridging substances generally not effective in themselves and must act upon already flocculated or nearly flocculated material. If a material cannot be easily coagulated by an inorganic coagulant, it is generally not susceptible to treatment by the organic polymers now available. Therefore, as already stated, these materials are only a partial aid to the basic sludge filtration program; but inasmuch as they are partially effective and as their possible variation is enormous, they offer great hope for the future.

Tests on Two Experimental Organic Polymers

During the course of the test, two experimental polymers were submitted by one large chemical manufacturer. They were apparently ionic materials which could react directly with the sludge particles and required no prior or subsequent coagulation by inorganic coagulants. They were usable by themselves at dosages of 0.01 per cent or less and were so effective that none of the test methods was adequate to show their true potential. That is, coagulation was so complete that yields well beyond the capabilities of the test equipment were obtained. In fact, most commercial vacuum filtration equipment available today would be hard-put to utilize the potentialities of such a material.

As was true of other coagulants, the experimental polymers worked best on elutriated digested sludge, indicating that as ionic materials they were affected by the salts normally washed out in elutriation. However, they were also somewhat effective on unelutriated digested sludge, and raw sludges, indicating that research could lead to a polymer that would act upon these materials directly.

The experimental materials did a spectacular coagulation job, allowing easy dewatering. After coagulant addition, the internatant or interstitial water would literally run out of the particles, leaving a layer of clear water over a dense well-clumped mass of solids. The coagulated sludge could be filtered on a 5-mesh screen and a compressive roller, then used with virtually no loss in solids. The very fine, slimy, and compressible sludge solids were converted by the coagulant into

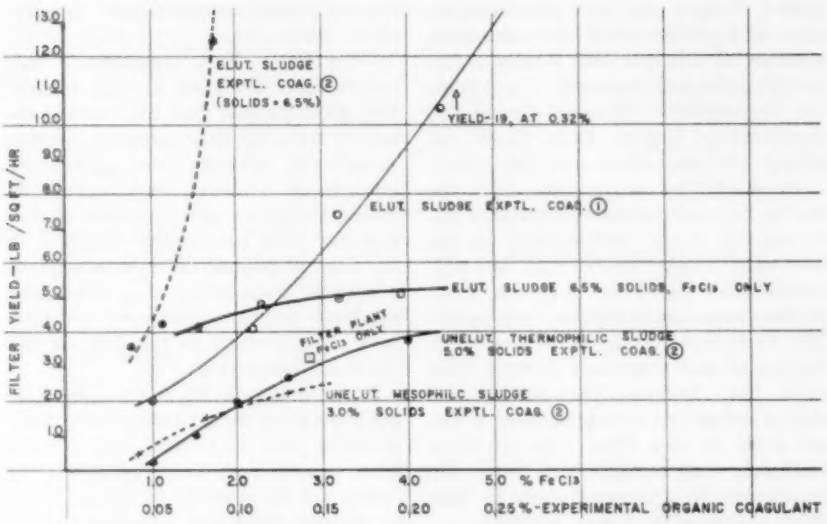
FILTER YIELD—LB/SQ FT/HR
ELUT. SLUDGE EXPTL. COAG. ② (SOLIDS = 6.5%)
YIELD-19, AT 0.32%
ELUT. SLUDGE EXPTL. COAG. ①
ELUT. SLUDGE 6.5% SOLIDS, FeCl₃ ONLY
FILTER PLANT FeCl₃ ONLY
UNELUT. THERMOPHILIC SLUDGE 3.0% SOLIDS EXPTL. COAG. ②
UNELUT. MESOPHILC SLUDGE 3.0% SOLIDS EXPTL. COAG. ②
% FeCl₃
%-EXPERIMENTAL ORGANIC COAGULANT

FIGURE 6.—Sludge filter rates with experimental synthetic organic coagulants (laboratory filter-leaf tests).

easily filterable solids with entirely different characteristics.

Figure 6 summarizes tests made with a 0.1-sq ft filter leaf on a large sample of elutriated sludge obtained from the plant system. It will be noted from the curve for $FeCl_3$ alone and from the filter plant data for that period that the sludge was easier to filter than the average material covered in Table VII. Experimental coagulants No. 1 and No. 2 are much more effective on elutriated digested sludge than the $FeCl_3$ alone, with No. 2 being essentially too efficient to be evaluated by the filter-leaf method.

If two gallons of sludge were coagulated and the filter leaf placed in the container, the filtrate was drawn from the entire sludge mass. In other words, the sludge near the filter cloth did not act as its own filtering medium as is usually the case. Three or more gallons would act in the same manner. The curves should thus be steeper than shown.

Figure 6 also shows that very low concentrations of experimental coagulant No. 2, with no added $FeCl_3$, were effective in some degree on unelutriated solids. The curves showing this action on unelutriated materials are perhaps the most significant, inasmuch as they indicate that a polymer can be found that would enable the filters to handle the total solids production.

Figure 7 presents an extension of the tests using a standard 1- by 1-ft model of the prototype production filters. It will be noted that 0.04 per cent of experimental coagulant No. 2 was equivalent to about 0.08 per cent of experimental coagulant No. 1, to about 2.5 per cent of $FeCl_3$, and to 0.045 per cent Separan and 1 per cent $FeCl_3$ with the sludge tested. As coagulant dosages increased, the yield from the experimental coagulants increased sharply, whereas that for the $FeCl_3$ started to flatten out. Only a very small quantity of experimental coagulant No. 2 was available for this test, but it can be seen that as in Figure 7 it is substantially better than experimental coagulant No. 1. It should also be noted that experimental coagulant No. 1 was tried on the 1- by 1-ft filter with nonelutriated di-

gested sludge. At 0.35 per cent dosage, a 2-psf/hr yield was obtained, whereas at 0.50 per cent dosage a 3.3-psf/hr yield was obtained. These rates for unelutriated digested sludge are significantly higher than those obtained with any other coagulant tried.

It should be emphasized that the curves for experimental coagulants No. 1 and No. 2 are undoubtedly on the low side. Cake could only be produced from the 1- by 1-ft test filter if the drum was turned at top speed. The underfilter mixer was operated at top speed and coagulant dosages were kept low, because the conditioned sludge dewatered so rapidly that it did not form its own filter mat. If these materials were commercially available, equipment designs would have to take their characteristics into account.

Experimental coagulants No. 1 and No. 2 unfortunately are not in production and there are no plans to make them available in the near future. Representatives of the manufacturer have indicated that there does not seem to be enough potential in the sewage treatment field to justify the cost of active research and development work.

Why then have unavailable materials been discussed at such length? The authors feel that the results obtained with the experimental polymer coagulants, wherein are shown potentials of filtering unelutriated digested sludge or raw activated sludge, together with the results obtained on filtering elutriated digested sludge on a routine basis using a commercially available polymer, constitute a significant breakthrough in the field of mechanical dewatering.

It is believed, therefore, that organic-polymer coagulants can be compounded that can drastically change what is now seen as a rather gloomy future for the disposal of sewage solids by vacuum filtration. Successful introduction of proper coagulants obviously would benefit operating agencies materially, as well as insure the future of vacuum filtration.

In short, filtration and its associated processes are at a crossroad and if the twin problems of cost and partial solids recovery cannot be solved, filtra-

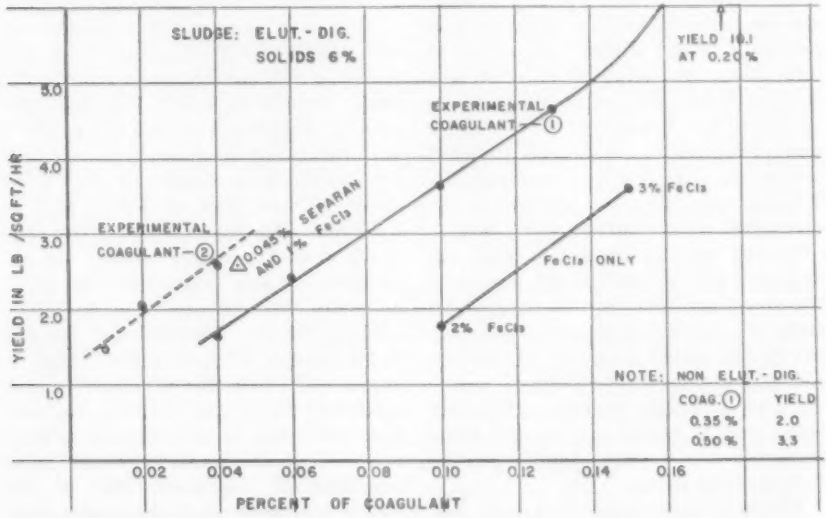

FIGURE 7.—Sludge filter rates with experimental synthetic organic coagulants (1- by 1-ft filter tests).

TABLE VIII.—Status of Vacuum Filter Installations, West Coast States*

Plant	Filter Status			Reason for Alternate Disposal, and Comments
	Regular Operation	Alternate Disposal Planned	Not in Operation	
California:				
Los Angeles	—	X	—	Operating costs
Monterey	—	—	X	Operating costs
Oceanside	—	—	X	Operating costs
Pasadena	—	—	X	Abandoned; operating costs
Sacramento	X	—	—	
San Diego	—	—	X	
San Francisco	X	—	—	Some study of alternate methods proposed
Santa Barbara	—	—	X	
Oregon:				
Albany	—	X	—	Operating costs
Coos Bay	—	—	X	Operating costs
Corvallis	—	X	—	Operating costs
Eugene	—	—	X	Operating costs
Washington:				
Bellingham	X	—	—	Over 10% $FeCl_3$ dosage
Bremerton	X	—	—	Partial operation; improvised drying beds used; cheaper
Enumclaw	X	—	—	
Kirkland	X	—	—	Filtration most expensive operation in plant
Seattle, S.W.	New plant, no data			
Spokane	New plant, no data			
Tacoma	—	—	X	Operating costs

* No vacuum filters installed in Idaho.

tion will increasingly be excluded from treatment designs.

Present Status of Filtration in West Coast States

As the dimensions of the solids removal problem at Hyperion became more apparent, an attempt was made to determine if this were a unique case. That is, were the conclusions as to the suitability of the basic process widely at variance with the experience of others? It was especially desired to determine whether other agencies were able to remove all their sludge solids, or whether, as at Hyperion, a large portion was either recirculated back through the treatment section or discharged with the effluent. It also was desired to know the economics of the process at other facilities.

With this in mind, all known users of vacuum filtration for sludge solids removal in the Pacific States were sent questionnaires. Table VIII summarizes the results. In 12 out of 19 cases enough difficulties had developed to lead to abandonment of the process or to consideration of abandonment. The following quotation from one reply is included because it vividly outlines the type of experience leading to discontinuance of the filtration operation in a plant:

> The plant was designed to dewater sludge by vacuum filtration and the filtration plant was operated during 1953. Very little trouble was experienced with the equipment, and high filter cake production rates were achieved. However, in spite of good technical results, the filtration process still cost about $3 per cubic yard of filter cake produced. An attempt was made to get back part of this money by selling the filter cake as a soil conditioner. It was advertised for sale and bids were invited. There were no takers. At this point an interesting experiment in com-

posting filtered sewage sludge with city garbage was carried on at the garbage dump by the sewer engineering section. The experiment demonstrated that sludge and garbage can be composted together to produce a useful organic conditioner. A proposal was made for the city to build a plant to undertake this on a commercial scale. However, because of uncertain costs and marketing conditions, the proposal was never carried out.

The bulk of the sludge from the filter operation was trucked to a natural bed on the east side of the plant. The sludge from this bed was then given out free to the public. It soon occurred to the plant personnel that the same end could be accomplished at much less expense by merely pumping the digested sludge to the beds and allowing it to dry out. The procedure was practiced in 1954 and subsequent years. The natural sludge beds were gradually improved by plant personnel to take care of increasing amounts of sludge. In July 1956 a tractor loader was acquired to load the dried sludge for the people. This service makes it much more attractive. This method of sludge drying and disposal is saving the city approximately $7,000 per year over the original filtration method.

This letter was received from a large community situated where annual rainfall conditions make bed drying about as difficult as could be found in this country; but beds were still considered to offer a better solution than their admittedly efficiently operating filtration process. Letters of a similar nature, reinforced by the data of Table VIII, showed that Hyperion was not the only plant having difficulty with the vacuum filtration method of sludge solids disposal.

Nearly all letters mentioned the cost of the process; many implied that the recovery of all of the solids removed by the treatment processes was virtually impossible. There was a general regret that equipment representing a considerable capital investment should remain idle, but a general feeling that there was no present alternative since filtration could not compete with other methods available. It is felt that this represents a trend that will continue unless the technological breakthrough represented by the synthetic organic coagulants is fully exploited. The sewage treatment industry, as a whole, should therefore have an interest in vigorously encouraging research in this area.

Summary

The mechanical dewatering installation at the Hyperion treatment plant has been in operation since 1950. Results have in general been disappointing and have not met design expectations. The primary responsibility for the inability to perform as designed had rested with the elutriation of the digested sludge and filtration of the sludge so prepared. The elutriation process removed the coagulant-demanding digestion products, but also acted to selectively fractionate out the filterable portion of the solids by transferring the less filterable fine materials to the effluent, or to the sewage treatment process, where it imposed a serious additional load. As attempts were made to recover more solids from the elutriation tanks, the percentage of fines retained increased, and filtration became increasingly difficult. It was therefore impossible to filter more than about 65 per cent of the digested sludge production on the installed equipment.

Attempts to improve filtration by manipulation of the mechanical equipment led to only minor improvements. Physical treatment of the sludge was likewise of little help. Coagulants offered the greatest promise and as a result a great deal of effort was expended in testing them. It was found that a filter leaf or a small prototype of the production filters gave the results most consistent with actual production expectations.

Utilizing these test instruments, extensive screening of available coagulants was accomplished. There was little benefit in most, but it was found that certain of the new synthetic polymer coagulants were adaptable to the sludge coagulation field. The word

"adaptable" has been used advisedly, inasmuch as it was a happenstance that they worked on sludge at all. Development work had been aimed at the coagulation of mineral slimes, coal fines, and other more valuable materials.

One of the commercially available synthetic polymer coagulants has been in production use at Hyperion for more than 2½ years. During this time it is estimated that about 25 per cent of the coagulant cost has been saved. Equipment installation enabling use of the material was accomplished at a minor cost and no problems have developed from the use of the material.

In the course of the evaluation of the synthetic polymers, two experimental coagulants were submitted and were found to perform in an amazing manner. These were apparently very long chain ionic materials, which could both coagulate the sludge and bind it into large discrete particles by its bridging action. Elutriated digested sludge so treated dewatered in spectacular fashion, producing yields of up to 30 psf/hr. These coagulants were also capable of dewatering unelutriated digested and raw activated sludges, suggesting that if properly compounded they could make the elutriation step unnecessary, allowing all solids to be removed on the filters and thus preventing the loss of solids overflow from such systems. Development of materials capable of effective action on all types of sludges normally produced represents a significant technical breakthrough in the field of mechanical dewatering. Inability of the manufacturer to supply more than experimental samples has limited the work, but the data are nonetheless felt to warrant this conclusion.

Such a breakthrough is necessary, as a survey of West Coast vacuum filter installations found that in a majority of cases the filters are no longer used. Trends are toward simpler, cheaper methods of handling 100 per cent of the solids produced. This is traceable to the need to find a suitable method of producing a non-compressible, easily filterable sludge, rather than to any fundamental lack in the filtration equipment.

Acknowledgments

Appreciation is expressed to G. A. Parkes, Chief Engineer, Sewage Treatment Division, and to Norman B. Hume, Assistant Director, Bureau of Sanitation, Los Angeles, Calif., for their active interest in and contribution to the investigations reported, as well as for their constructive criticism of the manuscript. The work of George Filias, Frank Wada, and John R. Stanton, Chemists of the Hyperion plant laboratory, in obtaining and interpreting much of the experimental data, is acknowledged. Particular appreciation is also expressed to the employees operating the mechanical dewatering facilities at the Hyperion plant. Their keen interest in process improvement and close attention to operating details aided the investigation immeasurably.

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MODIFICATION OF THE TRACER MEASURING METHOD IN SETTLING BASINS

By L. Muszkalay and I. Vágás

Scientific Researchers, Budapest, Hungary

This paper discusses the results of theoretical and experimental investigations conducted by the authors in 1953 and 1954 on the flow conditions in settling basins. The studies were divided into: (a) investigations of the tracer measuring method and (b) investigations to determine the hydraulic efficiencies of different types of settling basins.

Determination of Flow Wave

The method of determining the "flow wave" is well known and is described in the literature. Briefly, the tracer, an aqueous solution of salts, dyes, or radioactive materials, is quickly dosed into the inlet of the basin. By the aid of samples taken from the outlet of the basin, variations in the concentration of the tracer with time can be determined. The curve illustrating this variation (Figure 1) has been designated the "flow wave."

Many researchers in this field have indicated that the form of the flow waves may be influenced by the tracers used. In the authors' use the different tracers showed different characteristics, but it was observed that even with identical flow conditions and tracers the flow waves had different forms, caused by the varied dosing periods of the tracers. This is shown by Figure 2, which has three flow waves determined with the same tracers under identical conditions of form of basin, discharge, velocities, times of throughput, etc., the only variable being time of dosing of the tracer.

Table I gives characteristics of these three flow waves. In connection with both Table I and Figure 2, T is the time of dosing of the tracer, t_h is the time to reach the half-area of the flow wave, and t_c is the mean throughput time as calculated from V/Q_c, where V is the total volume of the basin and Q_c is the constant discharge.

Where hurried dosage was involved,

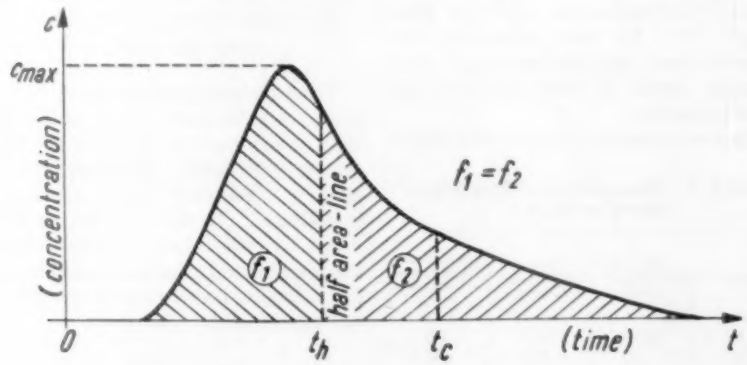

FIGURE 1.—Flow wave and its characteristic data.

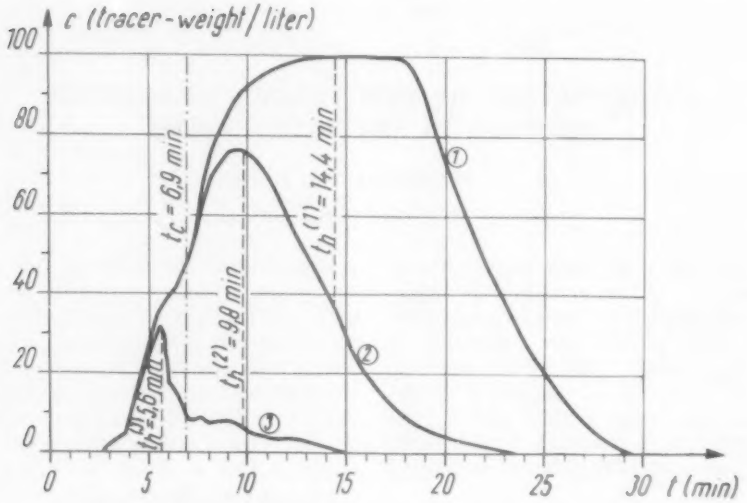

FIGURE 2.—Different time of dosage of the tracer liquid (T = 1.5, 5, and 15 min) results in flow waves of different forms.

it was not possible to determine accurately the true time of dosage at the basin inlet. As a result, there is no true uniformity of the flow waves and the observations lead to the conclusion that the hydraulic characteristics derived from the flow wave are not necessarily fixed.

Determination of Flow Diagram

To standardize the tracer method, the authors have devised and proposed a new method of tracer measuring, called "Determination of Flow Diagram" (1). In this procedure the tracer is dosed into the basin inlet over a longer period of time, but with the same intensity.

The concentration of tracer in samples taken at regular intervals from the outlet of the basin varies with time, the variation being described by $c = ct$ (see Figure 3), in which values of c are increasing to a constant value, c_r. A condition of this constant-value state is:

$$T \geqq t_n - t_o \quad \ldots\ldots\ldots (1)$$

in which

T = period of dosage of the tracer with same intensity;
t_n = time of throughput of the slowest water particle; and
t_o = time of throughput of the fastest water particle.

The constant concentration, c_r determined at the outlet is established as that determined at the inlet after dosing by the tracer. However, the concept of "relative concentrations" is introduced. In this concept, water not dosed by tracer has a relative concentration of 0 and all other concentrations are calculated as a ratio related to the untraced water. Thus:

$$c_r = \frac{Q_a c_a}{Q_e} \quad \ldots\ldots\ldots (2)$$

TABLE I.—Characteristics of Flow Waves Shown in Figure 2

Curve	Time of Dosing, T (min)	Time of Half-Area, t_h (min)	Calc. Mean Throughput Time, t_c (min)
1	15.0	14.4	6.9
2	5.0	9.8	6.9
3	1.5	5.6	6.9

in which

Q_a = discharge of the dosed tracer liquid;
Q_e = total discharge of the basin ($Q_a \ll Q_e$);
c_a = concentration of the tracer liquid before dosage; and
c_r = concentration of traced water at the inlet after the beginning of dosage.

The experiments reported here confirmed the belief that the increasing part of the flow diagrams is fixed, the amount of the dosed tracers having no influence on it. Therefore, the flow diagram is suitable for determining the true hydraulic characteristics of the settling basins. Some of the possibilities of using the flow diagram for this purpose are described in the following discussion.

Determination of the Water-Carrying Volume

Proposition:—The area outlined by the coordinate-axes, by the flow diagram, and by the horizontal line $c = c_r$ (Figure 3), is proportionate to the water-carrying volume of the basin. The water-carrying (active) volume is defined as the total volume of the basin minus the volume of stagnant water particles.

Verification:—Movement of traced water particles is a temporary movement in a permanent flow. The equation of temporary movements described with the masses of tracer is

$$Q_e t c_r - Q_e \int_o^t c(t)dt = c_r V_t \ldots (3)$$

where:

t = time calculated from the start of the tracer dosage, and
V_t = volume filled by traced water of concentration c_r.

Further, from Figure 3, if $t = t_x$, and $c(t_x) = c_r$, then V_t = the water-carrying volume (the active volume) of the basin. From Equation 3:

$$V_t = \frac{Q_e}{c_r}\left[c_r t_x - \int_o^{t_x} c(t)dt\right] \ldots (4)$$

Figure 3 shows that

$$c_r t_x - \int_o^{t_x} c(t)dt = \int_o^{c_r} t(c)dc \ldots (5)$$

where $t = t(c)$ is the inverse function of $c = c(t)$.

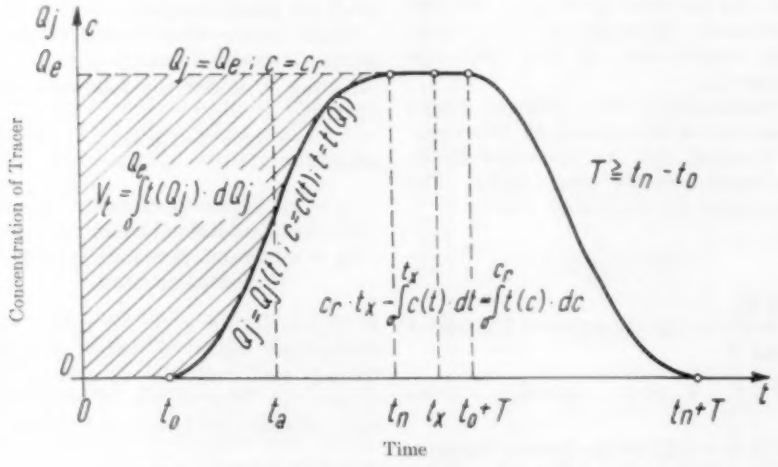

FIGURE 3.—Determination of the water-carrying volume (V_t) by the aid of the flow diagram.

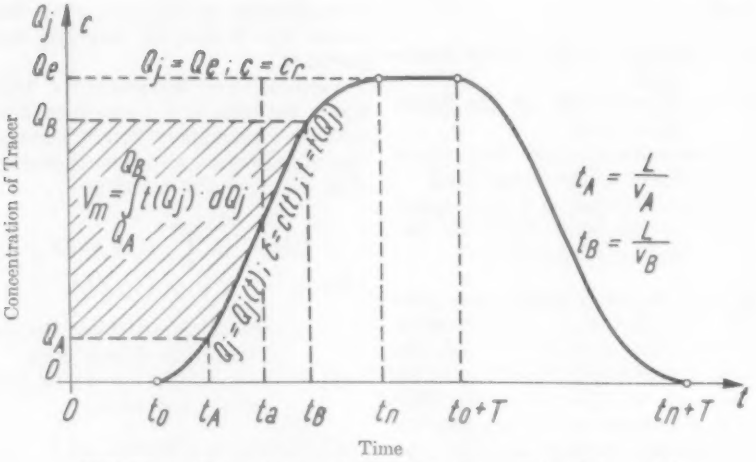

FIGURE 4.—Determination of the useful volume (V_m) and the useful discharge ($Q_B - Q_A$) by the aid of the flow diagram.

Equation 5 can be verified mathematically. From Equations 4 and 5, if values Q_e and c_r are given:

$$V_t = \frac{Q_e}{c_r}\int_o^{c_r} t(c)dc \quad \ldots\ldots (6)$$

Q.E.D.

The Flow Diagram as the Diagram of Traced Discharges

Proposition:—The function $c = c(t)$ and the function $Q_j = Q_j(t)$ are proportionate. Q_j is the traced discharge (the traced part of the total discharge Q_e).

Verification:—The effluent tracer mass can be determined by two ways. It is equal, first, to the value $Q_e c(t)$, and second, to the value $c_r Q_j(t)$. The two values are also equal, thus:

$$c(t) = \frac{c_r}{Q_e} Q_j(t) \quad \ldots\ldots (7)$$

Q.E.D.

As the result of combining Equations 6 and 7

$$V_t = \int_o^{Q_e} t(Q_j)dQ_j \quad \ldots\ldots (8)$$

where $t = t(Q_j)$ is the inverse function of $Q_j = Q_j(t)$. From Equation 8 the real mean throughput-time (t_m) can be determined:

$$t_m = \frac{V_t}{Q_e} = \frac{\int_o^{Q_e} t(Q_j)dQ_j}{Q_e} \quad \ldots\ldots (9)$$

Determination of the Useful Volume for the Sedimentation

Proposition:—The shaded area on Figure 4 and the useful volume for the sedimentation of prizmatic-form basins (V_m) are proportionate.

Verification:—The "useful volume" is the volume of water particles of velocities v, under the following conditions:

$$v_B \leqq v \leqq v_A \quad \ldots\ldots (10)$$

where

v_A = maximum permissible velocity for sedimentation,

v_B = minimum permissible velocity for sedimentation.

It is possible for v_B to be zero. The throughput times of water particles flowing with velocities v_A and v_B are t_A and t_B. The length of horizontal basin of prismatic form is L. Thus:

$$t_A = \frac{L}{v_A} \quad \ldots\ldots (11a)$$

and

$$t_B = \frac{L}{v_B} \quad \text{.....(11b)}$$

If the value $Q_j(t_A)$ is designated as Q_A and the value $Q_j(t_B)$ as Q_B (see Figure 4), can be described:

$$V_m = \int_{Q_A}^{Q_B} t(Q_j)dQ_j \quad \text{.....(12)}$$

Therefore, the useful volume and the shaded area on Figure 4 are proportionate. Q.E.D.

Interpretation of Hydraulic Efficiencies

By the aid of the Equations 8 and 12 three hydraulic efficiencies can be interpreted:

$$\eta_1 = \frac{V_t}{V} \quad \text{.....(13a)}$$

$$\eta_2 = \frac{V_m}{V} \quad \text{.....(13b)}$$

$$\eta_3 = \frac{Q_B - Q_A}{Q_e} \quad \text{.....(13c)}$$

The first efficiency is also suitable to calculate the effect of short-circuiting. It shows the relative proportion of the total volume of the basin to the water-carrying (active) volume.

The second efficiency shows the relationship of the total volume to the useful volume for sedimentation design purposes.

The third efficiency shows the relationship of the total discharge to the useful discharge for sedimentation design purposes.

Determination of Hydraulic Efficiencies of Different Types of Settling Basins

The hydraulic efficiencies of different types of horizontal basins were determined by the aid of flow diagrams. The tests were made in the laboratory using models which were scaled 1:10. Tap water and methylene blue tracer dye were used. The tracer liquid was dosed into the inlet of the model basins

TABLE II.—Summary of Results from Tests for Hydraulic Efficiencies of Laboratory Settling Basins

Test No.	Basin Length, L (cm)	Basin Width, B (cm)	Water Depth, M (cm)	Basin Volume, V (l)	Discharge, Q_e (l/sec)	Calc. Mean Throughput Time, t_s (sec)	Max Permiss. Velocity, V_A (cm/sec)	Min Permiss. Velocity, V_B (cm/sec)	Min Permiss. Throughput Time, t_A (sec)	Max Permiss. Throughput Time, t_B (sec)	Mean Real Throughput Time, t_m (sec)	Water-Carrying Volume, V_t (l)	Useful Volume, V_m (l)	Useful Discharge, Q_m (l/sec)	Hydraulic Effic., η_1* (%)	Hydraulic Effic., η_2† (%)	Hydraulic Effic., η_3‡ (%)
1	140	60	25	204	0.460	437	0.632	0.158	221	886	181	84.2	35.5	0.115	41.4	17.4	25.0
2	127	60	25	187	0.460	406	0.632	0.158	200	802	291	134.0	107.5	0.280	71.6	57.5	60.9
3	129	60	25	189	0.460	411	0.632	0.158	204	816	350	160.5	160.1	0.456	85.0	84.9	99.2
4	100	60	32	127	0.056	2,280	0.088	0.022	1,140	4,560	1,968	108.5	53.6	0.023	86.4	42.1	41.1
5	100	60	32	127	0.056	2,280	0.088	0.022	1,140	4,560	2,208	123.0	63.6	0.030	96.7	50.1	54.6
6	100	60	32	127	0.056	2,280	0.088	0.022	1,140	4,560	2,136	119.0	106.5	0.044	93.6	83.9	78.6

* See Equation 13a.
† See Equation 13b.
‡ See Equation 13c.

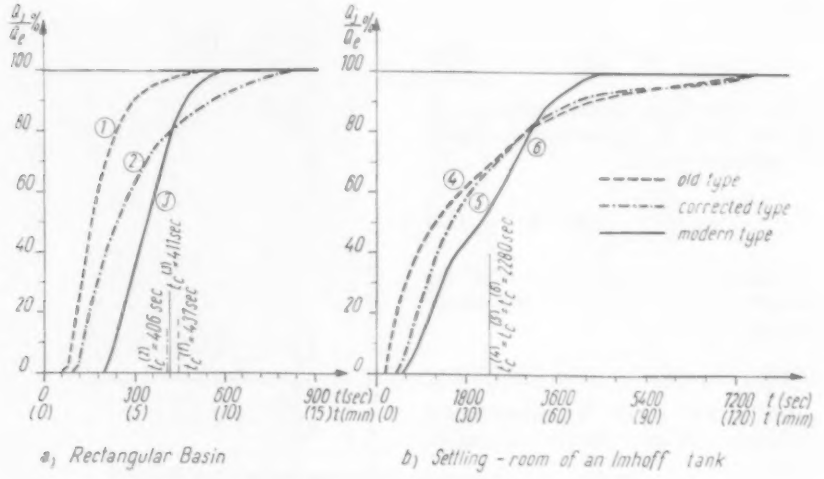

FIGURE 5.—Flow diagrams for the experimental tests.

over an extended period (2) (3). The samples were taken from the outlet tube.

Table II summarizes the results from six runs of the test basins. Runs 1 to 3 included three variations of a rectangular, prizmatic horizontal basin. Runs 4 to 6 used the settling room of an Imhoff tank, with a cross-section of double-triangle form. The water distributing inlet systems were different for the various runs.

Test No. 1 used a horizontal basin of an earlier type (old type). A weir distributed the influent at the inlet. The distribution of the influent was not uniform. As a result short-circuiting was observed in the basin.

Test No. 2 used an improved horizontal basin (corrected type). The influent was distributed by four "T"-shaped tubes.

Test No. 3 made use of a further improved horizontal basin wherein the influent was distributed by special spherical baffles (modern type).

Test No. 4 was conducted in an earlier standard Imhoff tank (old type). The influent was distributed by weirs; however, there was no short-circuiting.

Test No. 5 was carried on in a modified Imhoff tank in which the influent was distributed by six "T"-shaped tubes (corrected type).

Test No. 6 used a further modified Imhoff tank in which the influent was distributed by special spherical baffles (modern type).

The flow diagrams determined from the six tests are shown in Figure 5.

The results amplified the desirable characteristics of the modern types. Figure 5 shows that the water-carrying volume of the modern or corrected types is larger than that of the older types.

Summary

1. On the basis of these experiments the flow wave was indicated to be unsuitable to accurate measures. The characteristic numbers derived from the flow wave have no satisfactory physical base.

2. It is indicated that the flow diagram is suitable to determine the hydraulic characteristics of the settling basins. The tracer liquid is dosed into the inlet of the basin during an extended period, thereby obtaining a concentration of lasting intensity. By utilizing this procedure the form of the

increasing part of the flow diagram is not influenced by the concentration of the dosed tracer.

3. This flow diagram method is proposed for use in the hydraulic investigations of settling basins. By its use mathematically and physically defined hydraulic characteristics and efficiencies may be determined.

Acknowledgment

The studies reported in this paper were carried on at the I. Institute for Hydraulics, Technical University, Budapest, Hungary, under the general direction of Professor E. Németh.

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WALKER APPOINTED ADVISER IN BDSA

Odie E. Walker, Vice-President and Works Manager of U. S. plants for the Mueller Co., Decatur, Ill., was recently appointed Adviser to the Director, Water and Sewerage Industry and Utilities Division, Business and Defense Services Administration, U. S. Department of Commerce. Mr. Walker succeeds David L. Wright, who is returning to the Badger Meter Company of Milwaukee, Wis.

TRANSFORMATION OF SOME LIPIDS IN ANAEROBIC SLUDGE DIGESTION *

By H. Heukelekian and Peter Mueller

Department of Sanitation, Rutgers University, New Brunswick, N. J.

Grease is one of the major components of raw sewage sludge and the greatest reduction of volatile matter and production of gas is due to the decomposition of this component. Between the initial raw material and the end products innumerable transformations take place which are not thoroughly understood. The grease as well as proteins and carbohydrates are transformed into lower fatty acids, which in turn are converted to methane (1)(2).

During acid fermentation grease is decomposed to a certain extent, but it is not converted to gas; instead it accumulates as volatile acids. In alkaline digestion these volatile acids do not accumulate to any extent and the destruction of grease is accompanied by gas production. Acetic, propionic, and butyric acids have been shown to be produced during the digestion of sewage sludge (2).

There are possibly two rate-controlling factors in the degradation of fats into methane: (a) the adsorption of higher fatty acids into the cell at the beginning of the reaction chain, and (b) the accumulation of volatile acids, with subsequent lowering of the pH value and resultant inhibition of methane fermentation toward the end of the reaction chain. There is evidence that high molecular fatty acids can be absorbed intact into the cell. Dispersion of the fats is also an important factor in the rate of digestion.

This paper is concerned with the transformation of higher fatty acids during the digestion of sewage sludge. Experiments were carried out with unseeded and seeded mixtures in batch and continuous-feed digestions.

Methods

Special analytical methods to carry on this study were developed, adapted, and evaluated. These methods have been presented elsewhere (3). The procedure entails separation of the higher saturated fatty acids from sludge, separation of the saturated from the unsaturated fatty acids, separation of the individual saturated fatty acids, and their quantitative determination.

The general scheme of analyses employed involved (a) the drying of sludge by chemical means ($MgSO_4 \cdot H_2O$), (b) extraction of the total greases, (c) separation of the greases into free fatty acids and the acid-free greases, (d) separation of the latter into unsaponifiable matter and ester fatty acids, and (e) analyses of saturated and unsaturated free and ester fatty acids using chromatography and ultraviolet spectroscopy.

Unseeded Digestion

Two experiments with unseeded domestic fresh solids were carried out to determine the changes in the lipid content during the acid production stage. The changes during the first 20 days of digestion of one of these experiments are reported in Table I.

In the initial raw sludge, grease represented about 27 per cent of the volatile solids. Of the 7,420 ppm total grease, 3,900 ppm (52.5 per cent) was

* Paper of the Journal Series, New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, N. J.

TABLE I.—Transformation of Lipids During the Acid Digestion Phase of Unseeded Sewage Sludge

Determination	Digestion Time		
	0 Days	8 Days	20 Days
pH	5.8	5.0	4.8
Total solids (%)	4.04	3.88	3.53
Reduction (%)	—	4.0	13.0
Volatile solids (%)	2.74	2.56	2.21
Reduction (%)	—	7.0	13.0
Total grease (ppm)	7,420	7,320	7,500
Reduction (%)	—	1.0	0
Acid-free grease (ppm)	3,900	3,150	3,470
Reduction (%)	—	19.0	11.0
Unsapon. matter (ppm)	1,340	1,320	1,220
Reduction (%)	—	2	9
Esters (ppm)	2,560	1,830	2,250
Reduction (%)	—	28	12
Free fatty acids (ppm)	3,040	3,870	3,580
Increase (%)	—	27	18
Iodine number	32.2	15.7	13.8
Tot. unsat. acids (ppm)	955	651	524
Reduction (%)	—	32	45
Total sat. acids (ppm)	2,085	3,219	3,056
Increase (%)	—	54	46
Monoenoic acid (ppm)	926	626	498
Reduction (%)	—	32	46
Dienoic acid (ppm)	28.6	24.8	26.5
Reduction (%)	—	13.0	7.0

acid-free grease and 3,040 ppm (41.0 per cent) free fatty acids. The acid-free grease fraction was composed of 1,340 ppm (34.3 per cent) of unsaponifiable matter and 2,560 ppm (65.7 per cent) of esters. There were 955 ppm (31.4 per cent) of unsaturated fatty acids and 2,085 ppm (68.6 per cent) saturated acids in the free fatty acid fraction. Monoenoic acid constituted 97 per cent of the unsaturated acids.

Digestion during the 20-day period, as measured by gas production, total solids, and volatile solids reduction, was negligible, as would be expected. It is significant, however, that the amount of total grease did not decrease markedly. Despite this, there was significant transformation of grease as indicated by: (a) substantial decrease in the acid-free grease, most of which was due to the decrease of the esters and only a small portion to the decrease in unsaponifiable matter (the level of acid-free grease and esters was, however, lower after 8 days of digestion than after 20 days); (b) substantial increase in free fatty acids, primarily due to the increase in saturated fatty acids (the origin of increase in the saturated free fatty acids could be ascribed to the hydrolysis of esters); and (c) mono-unsaturated fatty acids decreased and were hydrogenated to saturated fatty acids, as indicated by the decrease in iodine number.

Thus, the grease fraction undergoes transformation during the early stages of acid digestion without an appreciable loss in grease. The loss of volatile matter during this period can be ascribed, therefore, to the destruction of organic matter other than grease in fresh solids.

Seeded Digestion

Two seeded digestion experiments were run. Because in the first experiment the number of samples taken during the digestion period and the number of analyses were not as extensive as in the second, the results of the first experiment are not reported.

The raw and digested sludges were mixed in a ratio of 1:0.7 on volatile matter basis. A portion of the mixture was set up for gas measurement and two 5-gal carboys were set up for sludge sampling. The bottles were incubated at 20°C for 40 days.

The results are presented in Table II in concentration units of various constituents at the beginning and at the end of the digestion period, and in Figures 1, 2, and 3 as the percentage of the various constituents remaining at

TABLE II.—Lipid Content of the Sludge Mixture at the Start and End of Seeded Batch Digestion

Determination	Start	End
Total solids (%)	6.57	4.68
Volatile solids (%)	4.62	2.70
Total grease (ppm)	12,800	6,220
Acid-free grease (ppm)	5,470	4,743
Unsaponifiable matter (ppm)	3,820	3,810
Ester fatty acids (ppm)	1,600	588
Iodine number of unsat. ester fatty acids	73	68
Tot. unsat. acids of esters (ppm)	1,140	406
Monoenoic acids of esters (ppm)	990	350
Dienoic acids of esters (ppm)	114	46
Trienoic acids of esters (ppm)	7	6.5
Saturated ester acids (ppm)	460	182
Tot. free unsat. fatty acids (ppm)	6,200	1,220
Iodine number of unsat. free fatty acids	26	34
Tot. unsat. free fatty acids (ppm)	1,760	380
Monoenoic free fatty acids (ppm)	1,690	350
Dienoic free fatty acids (ppm)	70	30
Total free sat. acids (ppm)	4,390	565
Myristic acid (ppm)	90	15
Palmitic acid (ppm)	1,980	308
Stearic acid (ppm)	1,290	175

various intervals during the digestion period.

Gas Production

The digestion proceeded normally, as indicated by the fact that a gas yield of almost 700 ml per gram of volatile matter in the fresh solids was obtained in 40 days. The daily gas production (Figure 1) indicates that a peak occurred in 6 days and a secondary peak in about 20 days. The first gas peak occurred almost a day before the minimum pH value of 6.2 was reached. The pH value recovered rapidly and reached a level of 6.8 and above. Volatile matter reduction was slight during the first four days, but decreased thereafter sharply and fairly steadily until at the end of the digestion period it amounted to 40 per cent.

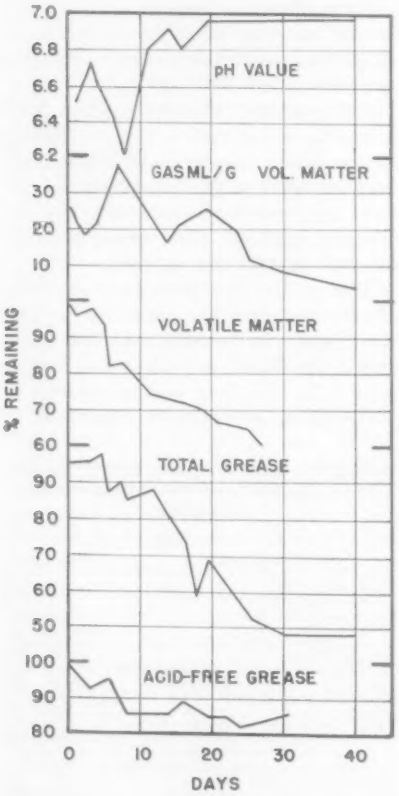

FIGURE 1.—pH, gas production, changes in volatile matter, total grease, and free grease in the digestion of seeded sludge mixtures.

Grease

The total grease, similarly, did not show an appreciable decrease during the first four days, but thereafter decreased somewhat irregularly, until at the end of digestion only 50 per cent of the original amount remained. The acid-free greases were reduced by only 14 per cent during the entire digestion period, while the unsaponifiable matter remaining (not presented) fluctuated erratically within the limits of 100 and 93 per cent.

Fatty Acids

The esters of fatty acids (Figure 2) decreased sharply from the beginning of digestion up to five days, at which time only 50 per cent of the original amount remained; thereafter there was a slower decrease, which resulted in a maximum reduction of 67 per cent. The total saturated ester acids showed an initial increase in three days, decreasing sharply to 56 per cent of the original amount in five days and somewhat more irregularly to 40 per cent of the original amount remaining at the end of digestion.

Monoenoic acid, which was the unsaturated fatty acid present in highest concentration, decreased rapidly during the first eight days of digestion to 40 per cent of its original concentration, with some fluctuations thereafter up to the end of the digestion period.

The iodine number of the unsaturated ester fatty acids decreased from an initial value of 73 down to 62.4 in 5 days, increased to 80.1 on the 8th day, decreased again to a level of 62 to 64 between the 14th and 24th days, and increased to 68.4 on the 30th day.

The total free fatty acids did not undergo a significant change in concentration up to 14 days of digestion

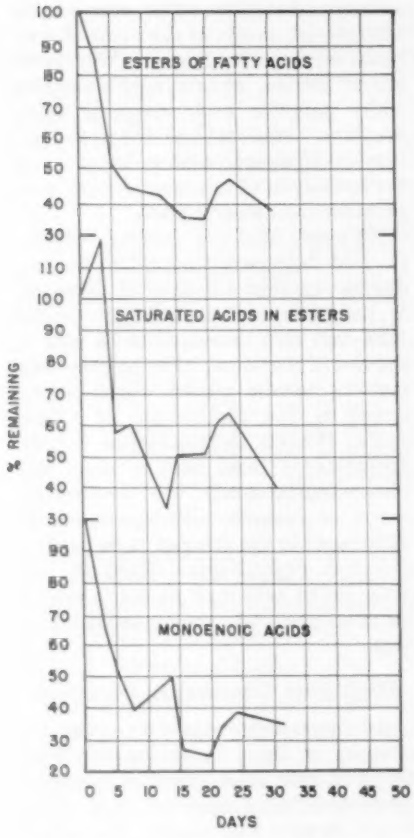

FIGURE 2.—Changes in the ester fatty acids in the digestion of seeded sludge mixtures.

(from an initial of 6,200 ppm to 5,600 ppm), but thereafter decreased rapidly to 20 per cent of the original concentration by the 30th day (Figure 3). The free unsaturated acids and their major component, the monoenoic acid, followed the same trend as the total fatty acids.

The total saturated fatty acids decreased only from 4,390 ppm to 3,880 ppm in the first days of digestion; thereafter they decreased sharply until only 13 per cent of the original concentration remained at the end of digestion. The two components of the free fatty acids that were present in the highest concentration were palmitic and stearic acids and their decrease followed the same trend as the total free saturated acids. Myristic acid was present only in 90 ppm concentration in the initial sludge mixture and it fluctuated up and down during the digestion until at the end, only 15 ppm were left.

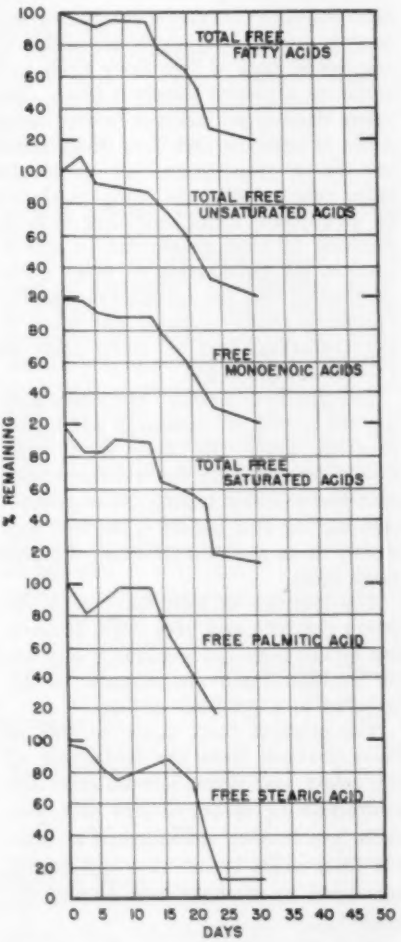

FIGURE 3.—Changes in the free fatty acids in the digestion of seeded sludge mixtures.

Seeded Digestion Discussion

The results show that unsaponifiable matter was not changed. The free fatty acids were reduced to a further extent than the esters of fatty acids. During the first week of digestion the esters of fatty acids disappeared sharply, whereas the free fatty acids remained more or less constant for two weeks. The free fatty acids decreased during the period when esters of fatty acids were fairly constant. These results indicate that esters are hydrolyzed to free fatty acids, which are added to the initial pool of free fatty acids and cause an apparent constant level. Because there is no increase in free fatty acids it appears that free fatty acids are being transformed at about the same rate as they are being produced by hydrolysis. The small but definite decrease in total grease can be attributed to the gasification of fatty acids. A part of the gas production during this early period is to be attributed to the transformation of fatty acids to volatile acids and gas.

Further hydrolysis of the esters during the period of increasing pH values proceeds after the first week more slowly, consequently the free fatty acids manifest a sharp decline. Gas production during this period is derived primarily from the conversion of the free fatty acids.

The increase in ester fatty acids between the 20th and 24th days, amounting to 210 ppm (13 per cent), appears to be significant and should be attributed to a synthesis of fats.

The original fatty acids, as well as those derived from the hydrolysis of the esters and those derived from the hydrolysis of carbohydrates and proteins, are further transformed to volatile fatty acids before they are finally converted to methane and carbon dioxide (2).

More than 80 per cent of the total free saturated fatty acids were palmitic and stearic acids. On a molar basis the palmitic acid was twice that of the stearic acid, except at the point of maximum methane production. Within the initial period, stearic acid decreased while palmitic acid remained fairly constant. This could be due to the conversion of stearic acid to palmitic, or the hydrolysis of esters producing more palmitic than stearic acids.

No lauric acid was detected. Myristic acid decreased from 90 to 58 ppm during the first six days of digestion. It then increased to 112 ppm on the 16th day, then decreased to 15 ppm at the end of digestion. The increase during the middle period might be ascribed to the degradation of higher acids. Because the production and degradation of these various acids take place simultaneously, whether they decrease or increase will depend on the differences in the rates of their production and degradation. Even the absence of an acid such as lauric acid is no proof that it is not an intermediate step.

High-Rate Continuous Digestion

An opportunity arose to study the changes in lipids in conjunction with the high-rate pilot plant experiments conducted by Torpey at New York City's Bowery Bay plant. The details of this operation are described elsewhere (4).

Samples of the raw sludge and of the sludge after various periods of digestion in the pilot unit were taken at two different times. The raw sludge consisted of a thickened mixture of 40 per cent raw primary and 60 per cent modified activated sludge.

In the first series the loading rate was 0.41 lb per cfd of volatile matter and gas production was 440 ml per gram of volatile matter added in the first series. The second series of samples was taken when the pilot digester was being loaded on 0.88 lb of volatile matter per cubic foot of digester per day. The total gas production was 600 ml per gram of volatile matter added.

TABLE III.—Concentrations of Sludge Components During High-Rate Digestion

Dig. Stage No.	Dig. Time (days)	pH	Solids (%)		Greases (ppm)			Acids (ppm)	
			Total	Vol.	Total	Acid-Free	Unsap.	Free Fatty	Ester Fatty
(a) High-Rate Digestion No. I									
Raw	0	5.5	6.04	4.55	10,600	4,601	2,261	4,702	1,390
1	10	7.3	3.12	2.05	2,660	2,110	1,675	589	470
8	22.5	7.4	2.23	1.40	1,722	1,009	1,170	53	280
9	33.5	7.5	2.37	1.45	1,815	1,685	1,340	84	365
(b) High-Rate Digestion No. II									
Raw	0	5.2	10.40	8.37	29,390	9,019	4,036	19,350	2,262
1	5	7.0	4.30	2.77	3,160	1,798	1,101	1,203	565
2	5.67	7.4	3.96	2.40	2,910	2,274	1,651	546	471
4	7	7.3	3.64	2.15	2,560	2,211	1,595	395	407

Component Concentrations

The concentration of sludge components during the various stages of digestion in the two series of tests is given in Tables III, IV, and V.

Volatile Matter and Grease

It is apparent that most of the destruction, both in volatile matter and total greases, takes place in stage 1. For high-rate digestion No. I, about 25,000 ppm (55 per cent destruction) volatile matter was destroyed, while about 8,000 ppm (75 per cent destruction) total greases disappeared in 10 days of digestion. In high-rate digestion No. II, volatile solids destruction amounted to 56,000 ppm (67 per cent) while total greases destruction amounted to 26,000 ppm (89 per cent) in the first five days of digestion. The free fatty acids were about 90 per cent destroyed and the ester fatty acids were about 70 per cent destroyed during

TABLE IV.—Concentrations of Individual Free Fatty Acids During High-Rate Digestion

Dig. Stage No.	Dig. Time (days)	Iodine Number	Acid (ppm)								
			Total Unsat.	Mono-enoic	Dienoic	Trienoic	Tetra-enoic	Sat. Calc.	Sat. Det'd.	Palmitic	Stearic
(a) High-Rate Digestion No. I											
Raw	0	33.5	1,460	1,250	137	22	43	3,260	—	—	—
1	10	38.4	193	180	9.2	3.8	0	302	—	—	—
8	22.5	87.1	—	—	—	—	—	—	—	—	—
9	33.5	92.8	63	41	18	0.7	1.9	22	—	—	—
(b) High-Rate Digestion No. II											
Raw	0	38.2	6,640	5,260	12.50	58	70	12,710	13,160	7,240	3,500
1	5	33.2	405	376	2.3	0.8	5.8	800	783	354	351
2	5.67	48.8	240	232	7.5	0	0	216	—	—	—
4	7	44.5	188	181	7.2	0	0	206	—	—	—

TABLE V.—Concentrations of Individual Ester Fatty Acids During High-Rate Digestion

Dig. Stage No.	Dig. Time (days)	Iodine Number	Acid (ppm)								
			Total Unsat.	Mono-enoic	Dienoic	Trienoic	Tetra-enoic	Sat. Calc.	Sat. Det'd.	Palmitic	Stearic
(*a*) High-Rate Digestion No. I											
Raw	0	50.6	802	636	132	10	23	588	—	—	—
1	10	62.3	295	274	13.5	3.2	3.9	175	—	—	—
8	22.5	74.9	195	165	24.5	2.9	2.9	88	—	—	—
9	33.5	91.1	321	279	37	4.0	1.2	44	—	—	—
(*b*) High-Rate Digestion No. II											
Raw	0	45.5	805	495	289	12	7.7	1,455	1,569	459	381
1	5	69.1	315	204	106	3.8	1.5	250	179	—	—
2	5.67	73.3	335	286	49	0	0	136	—	—	—
4	7	79.0	315	282	27	2.1	4.3	92	—	—	—

stage 1 in both experiments. The unsaponifiable matter underwent about 25 per cent destruction in digestion No. I, and about 70 per cent destruction at the higher loadings of digestion No. II. The destruction of these components continued during the later stages at a much decreased rate.

Fatty Acids

The iodine numbers of the free fatty acids in digestion No. I increased from 33.5 to 92.3 at the very end of digestion (Table IV). In high-rate digestion No. II there is also a significant increase in the iodine number of the free fatty acids.

The decrease in saturated free fatty acids was better than 98 per cent during the digestion; the destruction of mono-unsaturated fatty acids amounted to 95 to 97 per cent. At the end of stage 9 the fraction of dienoic acids in free fatty acids is double the initial proportion. The changes in the major individual free fatty acids were such that the molar concentrations of stearic, palmitic, and monoenoic acids, expressed as oleic acid, at the end of five days of digestion were about 1.3 millimoles per liter, regardless of their initial concentration (Table VI).

Percentage-wise, the destruction of the individual ester fatty acids was not as great as that for the free fatty acids. The total destruction of the saturated fatty acids combined as esters was 80 to 90 per cent; that of the unsaturated fatty acids was about 60 per cent. These changes are reflected by an increase of the iodine numbers from a value of 50 to about 90 at the end of stage 9.

At the start of digestion the ester fatty acids contain twice as much unsaturated as saturated fatty acids. At the same time this relative composition is reversed for the free fatty acids. The ratio of ester to free fatty acids also changes during digestion. In the fresh solids this ratio was 0.14:1 and in the ripe solids from the end (stage 9) the ratio was 4.35:1. Although the iodine numbers of the ester and free

TABLE VI.—Molar Concentration of Individual Free Fatty Acids During High-Rate Digestion No. II

Digestion Time (days)	Acid (millimoles/l)		
	Oleic	Palmitic	Stearic
0	18.7	29.2	12.3
5	1.3	1.4	1.2

fatty acids are almost the same at the end of stage 9, the relative composition of the individual fatty acids differs (Table VII).

High-Rate Digestion Discussion

The capacity for high-rate destruction during anaerobic digestion depends on proper environmental conditions. In Torpey's process these are engendered by frequent feedings, high concentration of sludge, and stirring. Not only do these conditions increase the possible loading rates, but also at higher loading there appears to be a higher percentage of destruction. Most striking about these results is the fact that grease destruction is greater at twice the loading. This is true for ester and free fatty acids, as well as for unsaponifiable matter. In the seeded digestion experiments no destruction of unsaponifiable matter was observed. Others, likewise, found little or no destruction of unsaponifiables. Yet there is a definite destruction of unsaponifiables observed during high-rate digestion and this destruction increased with an increased loading.

The explanation may lie in the facts that: (a) small, frequent feedings have the effect of increasing the seed-to-feed ratio; (b) increased concentration of sludge provides more surface for bacterial growth and thus a greater concentration of organisms, and it increases the buffer concentration; and (c) stirring contributes to the dispersion of the greases and other organic matter. These factors all contribute to better contact between the bacterial cells and the greases. Thus, at digester loadings between 0.1 and 1 lb per cfd volatile matter, the destruction of the various fat components does not seem to be limited by the effect of the molecular structures on the metabolism of the responsible organisms, but rather by the transport of relatively insoluble substances to the cell's surface.

The relative increase in unsaturated free fatty acids toward the end of digestion appears to be due to a greater decrease in saturated rather than unsaturated fatty acids and to an increase in dienoic acids. The relative increase in unsaturated ester fatty acids appears to be due to a greater decrease in saturated acids in the beginning and a net increase in mono- and poly-unsaturated fatty acids toward the end of digestion.

General Discussion

The study of some of the lipid components present in anaerobically digesting sewage sludge was carried out under essentially three different sets of conditions: (a) unseeded digestion, (b) seeded batch digestion, and (c) continuous-feed high-rate digestion. For the unseeded digestion the decomposition process ceased after the stage of acid production. The design of the high-rate digestion experiments was such that the initial phases and the phases leading to maximum gas production could not be studied. The phases following maximum methane production and volatile matter destruction, however, could be investigated. The seeded

TABLE VII.—Relative Composition of Individual Fatty Acids in Digested Sludge

Digestion Stage No.	Sample	Iodine Number	Acid (%)					
			Unsat.	Mono-enoic	Dienoic	Trienoic	Tetra-enoic	Sat.
9	Free fatty acids	92.8	73.6	49.1	21.4	0.8	2.3	26.4
9	Ester fatty acids	91.1	88.0	76.5	10.1	1.1	0.3	12.0

batch digestion experiments yield information as to what is happening to some of the lipids just before, during, and after maximum methane production.

If it is assumed, in accordance with Kaplovsky's (2) conclusion, that the differences in rates of all decomposition between the three types of digestions studied are due only to a difference in the environmental conditions rather than to a difference in fundamental biochemical mechanism, then the results and conclusions from each experiment can be integrated to present a unified picture as to the fate of lipids during the anaerobic decomposition of sewage sludge. The results of this study are discussed under the headings "Period of Acid Production and Liquefaction," and "Period of Gas Production and Stabilization." A simplified summary of the lipid transformations during anaerobic digestion is shown in Figure 4.

Period of Acid Production and Liquefaction

The unseeded digestion experiments show that no measurable reduction of total greases takes place during the first 20 days of intensive acid production. Esters are hydrolyzed to higher free fatty acids, however, and volatile matter is destroyed. During a similar period of digestion carried out under essentially the same conditions, Kaplovsky (2) found an accumulation of 5,000 to 6,000 ppm total volatile fatty acids. These facts together tend to indicate that the initial production of volatile acids during digestion is caused by the breakdown of organic matter other than lipids. In support of this conclusion, Heukelekian (5) has demonstrated the early and complete destruction of cellulose and carbohydrates during digestion.

Although the total greases do not undergo destruction during the acidification stage, the results demonstrate that the free fatty acids undergo a transformation. The increase in saturated fatty acids and the simultaneous decrease in unsaturated fatty acids (primarily monoenoic acid) indicate that partial but rapid hydrogenation of the mono-unsaturated fatty acids takes place. Hydrogenation of the unsaturated fatty acids present in ripe sludge also occurred upon mixing of the ripe sludge with fresh solids. It is postulated, therefore, that small quantities of hydrogen are formed, at least in the early stages of fresh solids digestion, and that this hydrogen, perhaps adsorbed on surfaces as atomic hydrogen, is responsible for the hydrogenation

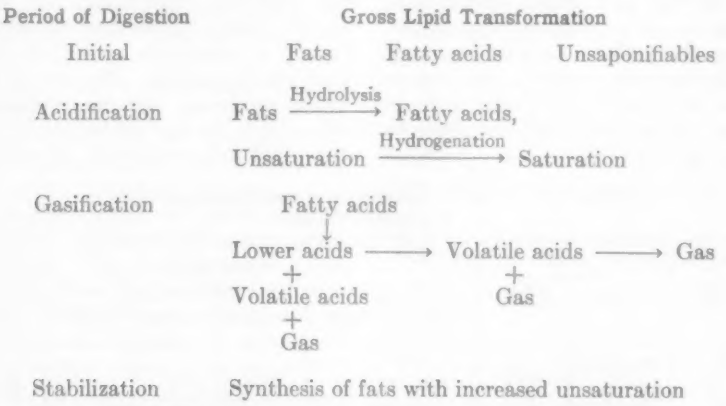

FIGURE 4.—Schematic summary of lipid transformations during anaerobic digestion.

of the unsaturated fatty acids. Although hydrogen has been found in digester gases only occasionally, and then in amounts less than 1 per cent of the total gas, the production of hydrogen during anaerobic fermentation of various organic substances is a well-demonstrated phenomenon (6)(7).

In seeded digestions, the acidification stage is rapidly followed by acid regression and extensive destruction of organic matter, so that some of the changes characteristic of the acidification stage alone cannot be observed. Even under these conditions, during the initial phase the total greases are destroyed only about 10 per cent, whereas the esters of the fatty acids are hydrolyzed about 60 per cent. Although an initial increase in unsaturation of the free fatty acids was observed, there was a decrease in the unsaturation of the fatty acids combined as esters. The ester acids contain twice as much unsaturated as saturated fatty acids. Thus, the fatty acids hydrolyzed from the esters have the effect of increasing the percentage of unsaturation of the free fatty acids. Thereafter, the percentage of unsaturation decreased again, to remain fairly constant throughout, until toward the end of the digestion period it again increased.

The question of whether or not the decrease in unsaturation under conditions of seeded digestion is due to hydrogenation or preferential removal of some unsaturated acids cannot be answered on the basis of these results. With the initial decrease of about 300 ppm total unsaturated fatty acids combined as esters, an increase of about 70 ppm total saturated fatty acids occurs. The processes underlying these changes may be postulated as follows. Initially, a portion of the ester unsaturated fatty acids is freed by hydrolysis, thus creating free unsaturated fatty acids. Other unsaturated fatty acids combined as esters are hydrogenated and thus contribute to the momentary increase in saturated ester fatty acids. Saturated fatty acids may also be freed by hydrolysis at this time, but because of their relatively small proportion, evidence of this reaction was not observed.

A study of the transformation of the individual free fatty acids during the first stage of digestion shows a difference in the behavior of stearic, palmitic, and myristic acids. Although the stearic acid concentration decreases, the palmitic acid concentration, after an initial drop, increases and remains at a high level. At the beginning of the decrease of palmitic acid, the myristic acid concentration increases 50 ppm, which is equivalent to about 70 per cent of the initial concentration. Lauric acid does not appear at all. According to Green (8), the accumulation of acids between C^{14} and C^{8} in chain length would not be expected during the beta oxidation of higher fatty acids. Thus, the rise in palmitic acid, the small accumulation of myristic acid, and the absence of lauric acid may be considered supporting evidence that beta oxidation of the fatty acids takes place during digestion.

Period of Gas Production and Stabilization

When optimum conditions for methane production have been established, all the fatty acids disappear rapidly and at about the same rate. For the seeded digestions, about the same 50 per cent decomposition of the initial quantity of free fatty acids occurred in eight days. In the high-rate digestions 90 per cent removal took place in 10 days or, at increased loadings, in 5 days. These observations indicate that these fatty acids serve equally well as sources of food for the organisms of sludge digestion. Similarity in the rates of destruction supports the view that these fatty acids are degraded by the same mechanism. The fact that, according to Kaplovsky (2), the maximum accumulation of volatile fatty acids occurs at a time during digestion

when maximum rate of destruction of the higher fatty acids is in progress, indicates that the degradation of the fatty acids contributes to the accumulation of volatile fatty acids; this, in turn, supports the theory that the fatty acids are broken down by the mechanism of beta oxidation during anaerobic sludge digestion.

If it is accepted that the fatty acids are split by the beta oxidation mechanism, it follows that the dehydrogenation steps involved are also operative. Whether the hydrogen thereby produced results in the formation of methane by reduction of CO_2 directly is not known. It is known that a methane organism can split caproate by means of beta oxidation to methane and acetate, with CO_2 acting as the hydrogen acceptor. It is not known whether an organism exists that can perform similar functions on fatty acids higher than caproic. Mylroie and Hungate (9) recently published that *Methanobacterium formicicum*, which produces methane specifically from hydrogen and carbon dioxide and does not utilize organic acids higher than formic, is abundantly present in digesting sewage sludge. Thus, it is not necessary to postulate that the same organism both dehydrogenates and produces methane. While other sludge organisms dehydrogenate fatty acids and other organic matter, *Methanobacterium formicicum* probably ferments the hydrogen produced to methane. In this way the beta oxidation of the higher fatty acids could contribute to the formation of methane.

At the peak of CH_4 production in seeded digestion, stearic, palmitic, and oleic acids were found to be present in a 1:1:1 molar ratio. The sample from stage 1, high-rate digestion No. II, comes from a sludge, producing maximum methane. In this sample too, stearic, palmitic, and oleic acids were found to be present in a 1:1:1 molar ratio. This observation is very similar to Kapolovsky's (2) observation that at a similar time during digestion of unseeded, limed, and seeded digestions the molar ratio of acetic to butyric acids was almost exactly 1:4, respectively. Although no specific explanation of this phenomenon can be given on the basis of the knowledge at hand, these facts point to the existence of steady state, which is characteristic of anaerobic digestion when environmental conditions are optimum for maximum methane production.

As gas production decreased in seeded digestion, an increase in the concentration of ester fatty acids was observed. A small increase in this component was also observed in the final stage of the high-rate digestion. The increase was due mostly to an increase in the unsaturated fatty acids. Toward the end of the digestions, the proportion of unsaturated fatty acids increased in both the ester and free fatty acids. The samples taken after stage 1 during the high-rate digestion experiments represent later stages of digestion than the last samples taken from the seeded digestions, as judged by the equivalent lapse of time after peak methane production. It has been noted that the iodine numbers of the fatty acids increase steadily and considerably toward the end of digestion. These changes may be due to the synthesis of cellular lipids. Because in a given sludge the increase in iodine number apparently reflects the stage of decomposition, the iodine number might prove useful as a parameter for the purpose of evaluating the degree of digestion.

Conclusions

From the study of some of the lipid components present in anaerobically digesting sewage solids, it is possible to enumerate the following conclusions:

1. The relative compositions of the major lipid components found in fresh and ripe sewage solids were as follows:

(a) The total greases of fresh sewage solids can contain 40 to 60 per cent free fatty acids, 20 to 40 per cent fatty acids combined as esters, and 15 to 20 per cent unsaponifiable matter.

(b) The total greases of ripe sewage solids can contain 1 to 20 per cent free fatty acids, 5 to 15 per cent fatty acids combined as esters, and 50 to 80 per cent unsaponifiable matter.

(c) The free fatty acids of fresh solids contain 25 to 45 per cent palmitic acid, 14 to 23 per cent stearic acid, 25 to 30 per cent monoenoic acids, and 2 to 6 per cent dienoic acids.

(d) The free fatty acids of ripe solids contain 20 to 35 per cent palmitic acid, 10 to 20 per cent stearic acid, 30 to 50 per cent monoenoic acids, and 2 to 20 per cent dienoic acids.

(e) The ester fatty acids of fresh solids contain 20 to 40 per cent palmitic acid, 10 to 20 per cent stearic acid, 20 to 60 per cent monoenoic acids, and 9 to 12 per cent dienoic acids.

(f) The ester fatty acids of ripe solids contain 10 to 20 per cent palmitic acid, 5 to 10 per cent stearic acid, 60 to 70 per cent monoenoic acids, and 5 to 10 per cent dienoic acids.

(g) Some fatty acid samples contained myristic acid from 1 to 5 per cent, trienoic and tetraenoic acids from traces to 2 per cent, and traces of lauric acid.

2. Destruction of total greases during the acidification stage of digestion was no more than about 10 per cent.

3. Organic matter other than fats contributes mostly to volatile acid accumulation during the stage of acid production.

4. Unsaturated fatty acids are hydrogenated to saturated fatty acids during the acid production stage of unseeded digestion.

5. Esters of fatty acids are rapidly hydrolyzed to free fatty acids during the period preceding maximum methane production.

6. The transformations observed in the relative concentrations of individual fatty acids during the period preceding maximum methane production fit with the theory of beta oxidation.

7. Seventy to 90 per cent destruction of the total fatty acids occurs during the period of maximum methane production.

8. Free fatty acids undergo 80 to 90 per cent destruction; ester fatty acids, 65 to 85 per cent; and unsaponifiable matter, 0 to 40 per cent during anaerobic digestion.

9. The individual fatty acids disappear at about the same rates during the period of maximum production.

10. At the time of maximum methane production the molar concentration ratio of oleic to palmitic to stearic acid is 1:1:1.

11. Synthesis of esters of fatty acids occurs toward the end of digestion.

12. Percentage of unsaturation of the fatty acids increases with digestion time and an increase in iodine number appears to be correlated with the extent of digestion of a given sludge.

13. The results support the conclusions based on information from the literature that the rate of grease destruction during digestion is limited by its degree of dispersion of and contact with the responsible organisms, rather than by the rate of cellular metabolism of the lipids at loadings up to at least 1.0 lb of volatile matter per cubic foot of digester per day.

Acknowledgment

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ROBERT A. GERBER JOINS FEDERATION STAFF

On July 1, 1957 Mr. Robert A. Gerber joined the Federation Headquarters staff. He will serve as Assistant Editor of SEWAGE AND INDUSTRIAL WASTES.

Mr. Gerber is a native of Pennsylvania. He received his Bachelor of Science degree in Sanitary Engineering from The Pennsylvania State University in 1948 and his Master of Science degree in Sanitary Engineering from Harvard University in 1955. He is a registered professional engineer in Mississippi.

His professional organization affiliations include membership in the Mississippi Sewage and Industrial Wastes Association, the American Water Works Association, and the American Society of Civil Engineers, of which he is an Associate Member. Prior to joining the Federation Staff, Mr. Gerber was Secretary-Treasurer of the Mississippi SIWA and a Director of the Jackson, Miss. Branch of ASCE.

Mr. Gerber has broad experience in sanitary engineering beginning with service in the Regular Corps of the USPHS for approximately four and one-half years. For approximately two years he served as a sanitary engineer with the Capitol Engineering Corp., Dillsburg, Pa., working on a number of municipal and industrial wastes problems. For the past three years Mr. Gerber has been with the Mississippi State Board of Health where he has had major responsibilities in the Federal grant program for sewage works construction and the development and study of raw sewage stabilization ponds. In addition to his work in the field of municipal sewage treatment Mr. Gerber has considerable experience in pollution investigations and water supply problems.

Active in the committee work of the professional organizations to which he belongs, Mr. Gerber was one of the organizers of the new Federation Member Association in Mississippi, as well as an early and steady supporter of the Mississippi water and sewage works operators' short course.

Mr. Gerber's formal training and experience will be invaluable to his editorial duties with the Federation.

AN APPARATUS FOR THE CONTINUOUS DELIVERY OF SMALL VOLUMES OF LIQUID *

By G. C. Ware

Water Pollution Research Laboratory, Stevenage, England

Since published information from outside the United States reaches a limited number of JOURNAL readers, the editors feel that from time to time there are previously published articles worthy of reprinting. This is such an item offering thoughts to those who have attempted to devise means of providing small liquid deliveries in the laboratory.

This paper was originally printed in *Laboratory Practice* by permission of the Department of Scientific and Industrial Research (British).

In experiments on the biological destruction of potassium cyanide it was required to dose a small filter with a sterile solution of potassium cyanide containing some suspended matter, at rates between 0.1 and 1 ml per hour. Conventional continuous-flow methods using needle valves or employing a capillary tube were found unsatisfactory, owing to blocking of the small orifice required, and intermittent methods such as rotating valves normally used for higher flow rates were not easily adapted to the micro scale and were difficult to maintain sterile over long periods.

In these experiments the solution of potassium cyanide was displaced from a reservoir by hydrogen and oxygen produced by the electrolysis of 0.5 M potassium sulfate (Figure 1), a solution shown by Lingane (1) to be suitable for this purpose. Rate of gas production and hence rate of flow is proportional to the current and is theoretically 1.671 ml/hr/ma; good agreement with this figure was obtained in practice. No ozone could be detected in the gases produced with currents of up to one milliampere, but at high current densities small traces of ozone were produced from the anode. By placing the anode in position X (Figure 1) only the hydrogen produced can pass into the fluid reservoir; interference due to ozone and the formation of an explosive gas mixture within the system are thus avoided.

Gases were generated at 40 S.W.G. (Imperial Standard Wire Gage)

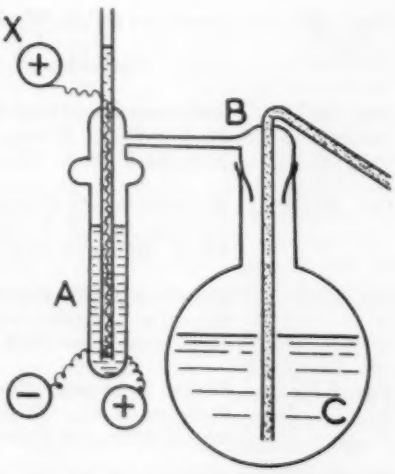

FIGURE 1.—Electrolytic cell for delivery of small volumes of liquid.

* Reprinted from *Laboratory Practice*, 6, 11, 656 (Nov. 1957), by permission of the publishers, United Trade Press Ltd., 9 Gough Square, Fleet Street, London, E. C. 4.

platinum wire electrodes sealed directly into micro-extraction condensers (A), with standard ground-glass fittings, sealed directly to a standard ground-glass washbottle head (B). The reservoir (C) was thus readily interchangeable and little glass-blowing was required for construction of the apparatus. The electrolyte was introduced through the open tube of the condenser, which also served to compensate for changes in atmospheric pressure. For greatest uniformity of flow the depth-to-volume ratio of the reservoir should be kept small to minimize differences in pressure caused by changes in liquid level.

Power requirements are small and by the use of dry batteries with a control rheostat the whole apparatus is self-contained and may be placed in an incubator.

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MEETINGS OF INTEREST

1958

Sept. 13–18 **American Chemical Society,** Atlantic City, N. J. R. M. Warren, American Chemical Society, 1155 16th St., N. W., Washington, D. C.

Sept. 15–19 **Instrument Society of America,** Automation Conference and Exhibit, Philadelphia, Pa. Fred J. Tabery, Conference and Exhibit Manager, 3443 South Hill St., Los Angeles, Calif.

Sept. 25–26 **Illinois Association of Sanitary Districts,** Illinois Hotel, Bloomington, Ill. Harry S. Macon, Clinton Sanitary District, Clinton, Ill.

Sept. 28–Oct. 1 **American Public Works Association,** Muehlebach Hotel, Kansas City, Mo. Donald F. Herrick, Executive Secretary, American Public Works Association, 1313 East 60th St., Chicago 37, Ill.

Oct. 13–17 **American Society of Civil Engineers,** Hotel Statler, New York, N. Y. W. H. Wisely, Executive Secretary, 33 West 39th St., New York 18, N. Y.

Oct. 20–24 **National Safety Congress and Exposition,** Conrad Hilton Hotel, Chicago, Ill. R. L. Forney, Secretary, National Safety Council, 425 N. Michigan Ave., Chicago 11, Ill.

Oct. 27–31 **American Public Health Association,** Kill Auditorium, St. Louis, Mo. Dr. Berwyn F. Mattison, Executive Secretary, 1790 Broadway, New York 19, N. Y.

Nov. 6–7 **Water Resources Conference,** State College of Washington, Pullman, Wash. William H. Knight, Technical Extension Services, Washington State Institute of Technology, Pullman, Wash.

Dec. 7–10 **American Institute of Chemical Engineers,** Netherland Plaza Hotel, Cincinnati, Ohio. F. J. Van Antwerpen, 25 West 45th St., New York 36, N. Y.

Industrial Wastes

EFFECTS OF RADIOACTIVE MATERIALS ON ANAEROBIC DIGESTION *

I. RADIOPHOSPHORUS

By Werner N. Grune, Donald D. Bartholomew, and Cecil I. Hudson, Jr.

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Discharge of radioactive wastes by the atomic energy industry and by the users of its products has given rise to new problems in stream pollution control (1). Present day discharge levels pose no immediate health problem. The continued and expanded use of radioactive materials may, however, result in increasing contamination and radioactive pollution of air and water.

The Atomic Energy Commission, recognizing the hazards, has instituted measures of control and maintains records of pollutants. Because of the increasing availability of radioactive isotopes to industrial, medical, and research users who may have less elaborate facilities for controlling their wastes, it may be expected that radioactive pollution will become more frequent and widespread. A survey of radioactive waste disposal practices (2) showed that more than 40 per cent of the users of radioactive materials dispose of them by discharge into the sewer system. These materials, after passing through a sewage treatment plant, eventually find their way into watercourses, some of which may be used as sources of water supply.

To detect possible increase in the radioactivity of streams at an early stage, methods of assay must be able to detect and to measure low-level radioactivity in water (3)(4). This requires the determination of activity of one-tenth or less the concentration of 1×10^{-7} microcurie (μc) per milliliter or 100 micromicrocuries ($\mu\mu$c) per liter according to the present tolerance limits for alpha, beta, or gamma activity recommended by the National Committee on Radiation Protection (5).

Significance in Water and Waste

To determine which radioisotopes are in water or waste, radiochemical procedures are employed. The sanitary engineering profession is familiar with many chemical and physicochemical techniques for the separation and removal of chemical contaminants. The main difficulty with decontamination is the extremely low levels at which radioactive materials in water may present a health hazard. The wide range in the maximum permissible concentrations (MPC) of the more hazardous fission product isotopes in air and in drinking water, besides P^{32} and Co^{60}, is easily seen in Table I.

The masses of pure radioactive materials to be dealt with are very small compared with the masses of other

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TABLE I.—Maximum Allowable Concentrations of Radioisotopes*

Radioisotope	Air (μc/ml)	Drinking Water		
		μc/ml	mc/gal	ppm
C^{14}	5×10^{-7}	3×10^{-3}	1.2×10^{-2}	6.5×10^{-4}
P^{32}	1×10^{-7}	2×10^{-4}	8×10^{-4}	7×10^{-10}
S^{35}	1×10^{-6}	5×10^{-3}	2×10^{-2}	1×10^{-7}
K^{42}	2×10^{-6}	1×10^{-2}	4×10^{-2}	1.5×10^{0}
Co^{60}	1×10^{-6}	2×10^{-2}	8×10^{-2}	2×10^{-5}
Sr^{89}	2×10^{-8}	7×10^{-5}	3×10^{-4}	3×10^{-9}
$Sr^{90}+Y^{90}$	2×10^{-10}	8×10^{-7}	3×10^{-6}	2×10^{-9}
Y^{91}	4×10^{-8}	0.2×10^{-1}	0.8×10^{-1}	8×10^{-6}
Nb^{95}	4×10^{-7}	4×10^{-3}	2×10^{-2}	1×10^{-7}
$Ru^{106}+Rh^{106}$	3×10^{-8}	0.1×10^{-1}	0.4×10^{-1}	1.5×10^{-5}
I^{131}	5×10^{-9}	3×10^{-5}	1×10^{-4}	2×10^{-10}
$Cs^{137}+Ba^{137}$	2×10^{-7}	1.5×10^{-3}	6×10^{-3}	9.5×10^{-6}
$Ba^{140}+La^{140}$	6×10^{-8}	2×10^{-3}	8×10^{-3}	2×10^{-8}
$Ce^{144}+Pr^{144}$	7×10^{-9}	4×10^{-3}	2×10^{-1}	6×10^{-8}

* References: (5) Table 5; (6) Tables IV and VIII.

wastes generally dealt with. A million curies of I^{131} contain only about 8 gm of the pure radioactive isotope, whereas a millicurie of Sr^{90} contains about 1 ppm of the material. Because the maximum permissible concentration of Sr^{90} in drinking water is about two-billionths of this activity, the high efficiency of decontamination which may be needed is apparent. The unique nature of the removal problem is therefore emphasized when the MPC-values are expressed in parts per million.

Conventional waste and water treatment processes may be effective in removing some radioactive elements. It is generally agreed (7) that current treatment processes will be useful only where the levels of radioactive materials are in the microcurie per liter (μc/l) range. For example, the maximum permissible concentration of Sr^{89} in drinking water is 7×10^{-5} μc/ml. To illustrate, the extremely low concentration involved, the maximum continuous discharge of Sr^{89} permitted into a source of water supply, based on a removal efficiency of 75 per cent through a downstream water softening plant, would be limited to 2.8×10^{-4} μc/ml, or 1.2×10^{-8} ppm.

It is reasonable to expect that processes now removing calcium, magnesium, iron, and manganese also will be effective in removing radioisotopes of the same elements under comparable conditions. On the other hand, there are many radio-elements that have not previously been dealt with in water and waste treatment practices. Many of the fission products fall into this category and for such elements, including the rare earths, the efficiency of conventional removal practices cannot be predicted. Consequently a dual problem exists: (a) to establish to what extent current treatment practices can decontaminate and produce a water or effluent meeting a new set of specifications, and (b) to develop new procedures from experimental evidence where present techniques fail.

Originally, conventional water treatment processes and biological sewage treatment methods were regarded as especially effective for the removal of specific radioactive materials. Laboratory and pilot-scale experiments (8) (9) (10) (11) (12) (13) (14) (15) (16) (17) (18) (19) (20) provide abundant evidence that this optimism was not justified without reservations. The literature is replete with the results obtained from the various processes

that have been investigated, including coagulation, sedimentation and filtration, addition of clay and metallic dusts, phosphate coagulation, ion exchange, softening, and specially devised procedures.

Thus, problems of water decontamination have held the interest of many and some definite limits have become established. The situation in waste treatment is somewhat different, as evidenced by the fact that there are fewer literature references (21)(22)(23)(24)(25)(26)(27)(28)(29).

Some of the more significant results from a number of studies for the removal of radioactive materials by conventional treatment methods are summarized in Table II. The only study with anaerobic digestion was performed at the University of Illinois (30).

The results from research investigations demonstrate that the removal of radioactive materials by biological concentration from liquid wastes may have only limited application.

Some radioactive materials are removed by biological assimilation. Typical of this phenomenon is the uptake of I^{131} and P^{32} by aerobic sewage treatment methods. Removal efficiencies for P^{32} vary over a wide range, largely dependent on the concentration of the stable isotope, or isotopic dilution. The degree of removal of I^{131} depends primarily on the biochemical relationship existing between radioactive element and biological system as the utilization or absorption on biological floc. It appears that where the only mechanism of removal is biological assimilation, removal efficiencies will not exceed 50 to 70 per cent (7).

TABLE II.—Approximate Range of Removal Efficiencies from Aerobic Sewage Treatment Processes

Radioactive Material	Removals (%)			Remarks
	Trickling Filter	Activated Sludge	Oxidation Ponds	
I^{131}	3–85	1–98	—[a]	Degree of removal dependent on conc. of I^{127} present[a]
P^{32}	20–30	20–30 3–46[b]	—[a]	—[a]
Mixed fission product	70–85[c] up to 90[d]	70–80	10–80	Fraction of activity adsorbed due to high degree of removal of individual scarce elements
Sr^{90}	11–99	11–99 75–80[e]	20	Presence of Ca and Mg considerably reduces uptake of Sr^{90}
Pu^{239}	75–95	75–80 90[f]	—	—

[a] Degree of removal influenced by concentration of stable isotope present:

(1) 98 per cent removal in presence of 0.001 ppm stable iodide concentration; only 20 per cent removal in presence of 0.1 ppm of stable iodide.

(2) The relative concentration between stable and radioactive phosphorus fixes the degree of P^{32} uptake from the waste.

[b] See (24); from 3.1 to 46 per cent removals by processes employing secondary treatment methods.

[c] See (25); removals of 2-yr-old fission products from synthetic sewage. Addition to the sewage of 100 ppm Versene resulted in complete elution of the previously adsorbed activity and reduced removal to zero. This effect also noted in activated sludge treatment.

[d] Up to 90 per cent removal with a recirculation ratio of 3:1.

[e] See (15); optimum removal of Sr^{90} at pH values above 8.0.

[f] Over 90 per cent plutonium removal obtained from laboratory wastes with a three-stage, countercurrent activated sludge pilot plant.

As an example of surface adsorption, Pu^{239} has been removed up to 95 per cent by both trickling filters and activated sludge (15)(26)(27). The extent of removal of fission products depends on the valence state of the element, and on the concentration of stable isotopes of the element concerned and of other elements having similar characteristics. The role of pH was also found to be an important factor, as during the removal of Sr^{90} (15). Those elements having valences of three or more (such as Ce^{144}) will be removed to a high degree, whereas the removal of Cs^{137}, with a valence of one, will be low. Generally, in situations requiring decontamination in excess of 90 per cent it is unlikely that biological systems are satisfactory. Biological treatment also has been suggested for wastes containing organic sequestering agents prior to chemical precipitation of the radioactive contaminants.

Where sewage treatment is necessary to abate stream pollution, the process may also serve to reduce the discharge of radioactive materials into the receiving stream and aid in maintaining discharges at levels which are non-injurious to the environment. It will also provide some protection against accidental discharges exceeding the recommended disposal levels (5). Furthermore, the need for the decontamination of radioisotopes in sewages and industrial wastes is a primary health problem for those concerned with the daily operation of a treatment plant. With these exceptions, there is considerable evidence that aerobic biological flocs and slimes have relatively limited capacity to assimilate mono- and divalent radioisotopes, particularly those which are soluble and abundantly present in the stable form.

Purpose of Experiments

These investigations were undertaken in an effort to establish the distribution of radioactivity from digested sludge, in order to safeguard personnel in sewage treatment plants from radiation hazards and to set tolerances for the final disposal of liquid wastes in accordance with allowable concentrations of radioactive materials which may enter streams. It was not expected that the anaerobic decomposition of sewage solids (sludge) would lend itself to the high degree of treatment or decontamination required of radioactive wastes to meet the present standards (5). It was necessary, however, to definitely establish the level at which radioactive materials, such as radiophosphorus (P^{32}) and radioiodine (I^{131}), as commonly discharged to sewage systems, would exert deleterious effects on the digestion process. Since it is realized that a dose in excess of 1,000 roentgens is generally necessary to destroy bacteria (31), sterilization of the sludge at normal levels of disposal was not expected, but significant effects might be found when high concentrations of radioactive isotopes were added.

However, in a heterogeneous culture, such as anaerobic sewage sludge, it is difficult to predict the effects due to radioactivity because sludge composition and microbiological population are not fully understood or known. Further complicating this problem are the day-to-day variations in flow and strength to which the average disposal plant is exposed, but which it must treat. It was therefore considered essential to establish the concentrations at which radioactive materials would interfere with the digestion process under various operating conditions. Should the process be upset, or fermentation be inhibited, this might result in a higher proportion of the radioactivity in the liquid phase and thus a larger portion of the activity being discharged to a river. In the case of other isotopes a greater percentage of the activity might become lodged in the sewage solids, which are

dried subsequent to treatment and often used as fertilizer or as a soil conditioner. The potential hazards of environmental contamination are clear.

It therefore became necessary to determine the relative concentration of radioactivity between the liquid and the solid component of the sludge after treatment for those cases where radiation effects had inhibited the proper functioning of the process; as well as for cases where insufficient activity was added to destroy the microorganisms or otherwise inhibit digestion.

From a comparison of these results the degree of decontamination afforded by anaerobic decomposition could then be assessed at levels below radiation damage, as well as the decontamination factor attainable from sludge digestion when the normal process was destroyed due to radiochemical and/or radiobiological damage. In the latter case the process would revert to a slurrying operation and any uptake of radioactivity would be primarily by contact adsorption rather than by biological assimiliation or uptake.

Variables and Parameters Measured

A number of qualitative parameters were measured to evaluate the effects of radiophosphorus (P^{32}) and radioiodine (I^{131}) on anaerobic digestion. Quantitative measurement of the gas production is a time-proven and practical measurement of progress of digestion. The rate of gas production or the reaction velocity constant, k, was obtained by least square analysis of fitting the data to a first-order reaction as an engineering approximation (32)(33). Simultaneously, the analysis also yields a value for ultimate gas production. The efficiency of gas production was expressed in cu ft per pound of volatile matter destroyed and the percentage reduction of volatile matter.

In addition to gas production data, volatile acids produced by the sludge were measured both at the beginning and at the end of each laboratory run. According to Buswell (34)(35), the volatile acids, which are intermediates in the decomposition of higher compounds, must not exceed a predetermined value, usually 2,000 to 3,000 ppm (calculated as acetic). If the volatile acid value is allowed to rise much above 2,000 ppm (as acetic), gas formation drops off, the quantity of acids increases rapidly, and usually within 24 to 48 hr all fermentation ceases. If digestion is impeded because of too much organic matter, or if a toxicant destroys microorganisms and therefore inhibits digestion, the formation of volatile acids (combination of formic, butyric, propionic, and acetic acids) will increase. When digestion proceeds satisfactorily the concentration of volatile acids generally does not exceed several hundred ppm. Therefore, changes of volatile acids concentration would be another indicator if the presence of radioactive materials inhibits the process.

It was considered important to obtain a continuous measurement and record of pH to study the progress of digestion and to compare radioactive sludges with corresponding controls. Because it is known that temperature exerts a distinct influence on the rate of digestion (36)(37), constant temperature conditions had to be maintained. To follow any variation of temperature this variable was recorded on a continuous 24-hr basis. The determination of total and volatile solids was in accordance with "Standard Methods" (38).

The measurement of these variables, including pH, volatile acids, and solids in the sludge, is normally done by taking samples from the digesters. However, with 16 digesters this procedure would have entailed a great deal of routine daily work. Therefore, it was deemed desirable to measure as many of the qualitative variables on a continuous basis as possible. This was not only desirable, but a necessity

with small laboratory digesters (2-l capacity) which, if samples had been withdrawn daily, would soon have been depleted of sludge. Furthermore, daily withdrawal of samples from the radioactive digesters would have exposed the personnel to more radiation than was considered prudent.

Continuous measurement of as many of the important variables and the development of new qualitative parameters to indicate other conditions in the digester, was a natural outgrowth of these considerations. The three techniques applied in this research were liquid conductivity to measure the breakdown of solids with digestion progress, oxidation-reduction potential to indicate the reactivity of the substrate, and qualitative analysis of the gases of decomposition by chromatographic methods. It was anticipated from the start that the development of these new techniques might also lead to their application to evaluate the effects of other than radioactive wastes and for operational control of the anaerobic digestion process.

Conductivity

Although the routine determination of total and volatile solids in sludge is possible but subject to considerable error (36), the analysis for suspended and dissolved solids of sewage sludge is even less satisfactory. Present methods are time-consuming and lack reproducibility. From preliminary experiments (39) it appeared that measurement of the liquid conductivity of sludge may be used to interpret the degree of breakdown of sewage solids as digestion proceeds.

The determination basically consists of a resistance measurement of a standard column of solution. It is performed with an a-c Wheatstone bridge to avoid changes in composition adjacent to the electrode or polarization. Specific conductance is the reciprocal of the resistance in ohms of a 1-cm cube of liquid at the specified temperature in mhos. A plot of specific conductance with an electrolyte concentration at constant temperature starts almost linearly, rises with concentration, and gradually decreases in rate until a maximum is reached. Because temperature greatly influences the conductance, the former should be recorded simultaneously. The laboratory measurements of raw, partially digested, and completely (90 per cent or more) digested sludges have indicated conductance values of approximately 1,000 to 2,500, and 5,000 micromhos/cm, respectively.

Oxidation-Reduction Potential

Many of the chemical and biochemical processes encountered in sewage and industrial waste treatment can be described fundamentally as oxidation-reduction systems. Although the measurement of the oxidation-reduction potential does not itself explain the nature of the systems at work, it is useful in the evaluation of magnitude and character of process changes.

The oxidation-reduction potential of a system, referred to the hydrogen electrode, is expressed by E_h. The greater the proportion of reduced substance present, the lower the value of E_h; conversely, the greater the proportion of oxidized substance, the higher will be the E_h value. Hood (40) found that when the molar concentrations of oxidant and reductant are equal, $E_h = E_o$, in accordance with the following equation:

$$E_h = E_0 + \frac{RT}{nF} \ln \frac{[\text{Ox}]}{[\text{Red}]} \quad \ldots (1)$$

Evaluating the thermodynamic constants and taking into account the difference between common and Naperian logarithms, the expression for the measured potential E_h referred to the hydrogen electrode and at 30°C

becomes:

$$E_h = E_0 + \frac{0.06}{n} \log \frac{[Ox]}{[Red]} \quad \ldots (2)$$

where n represents the number of electrons that participate in the potential system.

The hydrogen ion exerts a measurable effect on the redox potential (41). If the results from the potential measurements are to be properly interpreted, pH values should be obtained concurrently. Redox potential can be measured with a potentiometer, a platinum, and a standard reference electrode, usually a saturated KCl calomel cell. Measurements of the redox potential in an actively digesting mixture of sludge show a potential falling from + 100 mv to − 400 mv, indicating the presence of strong reducing conditions. An ORP electrode system has been developed in which the large area platinum electrode, in combination with rapid flow, effectively eliminates solution polarization (42). The design of the flow cell is unique, because it represents no obstruction to flow. This flow cell has been used for the continuous measurement of oxidation-reduction potentials in sludge for periods up to 150 days without any measurable polarization. Reproducibility of standard potentials within ± 5 per cent has been achieved.

Chromatographic Gas Analysis

Gas chromatography was applied to these investigations to resolve the components from sludge gas mixtures containing about 60 per cent CH_4 and 30 per cent CO_2, and smaller fractions of H_2S, NH_3, N_2, and water vapor. The purposes of qualitative and quantitative gas analysis were as follows:

1. To determine the relative concentration of methane and carbon dioxide at optimum digester performance and to check on the calorific value of the gas in the presence of various concentrations of radioactivity.

2. To identify and separate the various components of the gas mixture and to determine if any of the gaseous components become radioactive during digestion and possibly pollute the atmosphere.

Basically the chromatographic analyzer, previously described in more detail (43)(44), consists of a thermal conductivity cell in which a comparison is made between the temperatures of two electrically-heated filaments based on the difference of thermal conductivity between an unknown sample and a known standard gas; a column which separates the mixture so that the various components arrive at the detector at different times; a supply of carrier gas under pressure to push the sample through the system; and several auxiliary pieces of equipment such as flow meters, sample injection system, amplifier, and recorder.

Radioassays

To determine the distribution of the radioactivity in the liquid, solid, and gaseous phases of digesting sludge, it was necessary to employ specific counting techniques for each.

Direct counting of the liquid phase from a digester was done with a Marinelli beaker. The beaker was equipped with a dip-type counter and standardized for P^{32} and I^{131}. However, this method is better suited to the detection of gamma, rather than beta emitters. Laboratory assays to determine the concentration of activity in the solid phase were carried out by the evaporation technique. This method was also employed to analyze the liquid phase activity and to check on the Marinelli beaker technique. Therefore, the evaporation technique, rather than the Marinelli beaker, was used in determining most results.

Because of the relatively low activities in the gas phase, rather delicate

analytical techniques were necessary. The direct counting of radioactive gases was accomplished with a "continuously flushing ionization chamber." A vibrating condenser-type electrometer * has recently become available and will be used as a continuous gas monitor when C^{14} is studied.

Experimental Method

The fresh and digested sewage solids were obtained from the primary sedimentation basins and secondary digesters of the Clayton and Egan sewage treatment plants, Atlanta, Ga. The Clayton plant provides treatment for approximately 45 mgd of predominately domestic sewage. The Egan plant, with a standard-rate filter, provides complete treatment for 1.5 mgd of domestic sewage. Using samples from both plants varied the substrate to lend more general interpretation to the experimental results.

The sludge mixtures were prepared in the laboratory as soon as possible after collection at the plant, proportions of raw to digested solids being based on volatile matter content. To measure ORP, pH, and conductivity on a continuous basis, it was necessary to recirculate the sludge to prevent polarization of the electrodes. For this purpose specially blown glass digesters were provided with inlet and outlet arms. Tygon tubing with ⅜-in. ID was used for the recirculation flow line and proved quite satisfactory. The sludge was pumped by a specially designed hose-pump (45) and modified for sludges with concentrations of 4 to 8 per cent total solids (42). The requirements for the pump were quite stringent, as the sludge had to be moved through three electrode assemblies (ORP, pH, and conductivity) and returned to the digester without any changes in the substrate. Losses of CO_2 and CH_4 could not be tolerated and the entrainment of any air to the anaerobic system had to be prevented. Furthermore, extreme caution had to be exercised to prevent radioactive sludge escaping from the recirculating flow system at concentrations as high as 0.8 curie/liter, because any leak would have produced hazardous conditions.

The velocity of the sludge to prevent solution polarization was found to be critical for the redox potential cell. A velocity of about 5 fps was necessary to prevent polarization. Continuous recirculation of the sludge to flush the cells was unnecessary and a schedule of pumping four times daily for 30 min was found to be adequate.

For economic reasons it was not possible to equip all 16 laboratory digesters with these electrode systems. Complete instrumentation for each digester cost about $500, including amplification of cell signal and a single record on a multiple-point recorder.

Observations from a minimum of 12 digesters were considered necessary so that the data would lend itself to statistical analysis. Therefore, 12 were treated as batch digesters to make this data homogeneous. In the other four digesters the sludge was stirred (recirculated) to evaluate the effects of radioactivity during mixing and to obtain a continuous record of pH, ORP, and conductivity.

Therefore, most laboratory runs contain data from 16 digesters, 12 of which were treated as batch digesters. Results from the four recirculated sludge digesters cannot be directly compared.

To prevent clogging of the flow lines, all sludge had to be screened (¼-in. mesh) before charging the digesters. This procedure unfortunately entrained a great deal of air in the sludge, which worked to the detriment of early ORP observations; but this experimental disadvantage was overruled by the absolute requirement of preventing all possible flow-line breaks when dealing with radioactive sludge.

* Dynacon Electrometer, a product of Nuclear-Chicago.

TABLE III.—Experimental Conditions, Gas Production, and Volatile Matter Reduction for Radiophosphorus (P^{32}) Studies

Run	Period (days)	Date	Dig. No.	Experimental Conditions					Total Gas Prod.		Red. Vol. Matter (%)
				Sludge Vol. (ml)	Sludge Mixture	Inc. Temp. (°F)	Conc. KH_2PO_4 (ppm)	Conc. P^{32} (mc/l)	Ml per gm V.M. Added	Cu ft per lb V.M. Destroyed	
II	30	7/19/56	1	700	19:1	75	—	—	18.63	—	—
		↓	2		19:1		—	1	18.43	—	—
		8/21/56	3		3:1		—	—	—[a]	—	—
			4		3:1		—	1	47.25	—	—
			5		1.5:1		—	—	288.13	—	—
			6		1.5:1		—	1	272.63	—	—
			7		1:1		—	—	—[a]	—	—
			8		1:1		—	1	405.73	—	—
			9		0.5:1		—	—	227.27	—	—
			10		0.5:1		—	1	324.18	—	—
			11		0.25:1		—	—	273.97	—	—
			12		0.25:1		—	1	255.73	—	—
			13		1.5:1		—	—	24.09	—	—
			14		1.5:1		—	1	22.73	—	—
			15		1:1		—	—	88.73	—	—
			16	↓	1:1	↓	—	1	94.96	—	—
III	71	8/23/56	1	700	1:1	80	—	—	146.9	7.09	33.1
		↓	2				—	—	140.9	5.07	44.4
		11/2/56	3				14,300	—	24.96	2.54	15.6
			4				—	50	74.15	2.33	50.6
			5				28,600	—	17.41	1.43	19.3
			6				—	100	20.55	1.29	25.4
			7				57,200	—	9.53	—[b]	—[b]
			8				—	200	19.47	1.82	17.0
			9				114,000	—	—[c]	—[c]	—[b]
			10				—	400	16.12	7.46	3.46
			11				229,000	—	—[c]	—[c]	—[b]
			12				—	800	4.38	0.52	13.5
			13				14,300	—	14.50	—[b]	—[b]
			14				—	50	17.83	1.13	25.1
			15				57,200	—	11.28	1.00	17.9
			16	↓	↓	↓	—	200	27.04	4.28	10.1
IV	95	11/2/56	1	900	0.55:1	80	—	—	14.5	0.635	36.4
		↓	2				—	—	25.8	1.185	34.5
		2/5/57	3				7,930	—	96.15	2.62	36.0
			4				—	0.91	248.11	15.45	24.7
			5				15,900	—	1.64	0.100	21.9
			6				—	1.82	5.77	5.87	16.7
			7				31,800	—	1.26	—[b]	—[b]
			8				—	3.64	3.18	0.267	19.3
			9				63,600	—	1.21	—[b]	—[b]
			10				—	7.29	1.74	—[b]	—[b]
			11				128,000	—	0.22	—[b]	—[b]
			12				—	14.58	1.84	0.224	13.1
			13				7,930	—	2.97	0.235	20.3
			14				—	0.91	2.07	—[b]	—[b]
			15				31,800	—	4.48	—[b]	—[b]
			16	↓	↓	↓	—	3.64	2.68	—[b]	—[b]

[a] Leaks found in gas system.
[b] Solids determination, no volatile matter reduction.
[c] No gas produced.
[d] Pump line broke, spilling contents.
[e] Glucose.
[f] KH_2PO_4.

TABLE III.—*Continued*

Run	Period (days)	Date	Dig. No.	Experimental Conditions					Total Gas Prod.		Red. Vol. Matter (%)
				Sludge Vol. (ml)	Sludge Mixture	Inc. Temp. (°F)	Conc. KH_2PO_4 (ppm)	Conc. P^{32} (mc/l)	Ml per gm V.M. Added	Cu ft per lb V.M. Destroyed	
V	31	2/23/57	1	700	1:1	82.5	—	—	296	12.87	36.9
		↓	2	↓	↓	82.5	—	—	152	6.63	36.9
		4/2/57	3			81.7	7,385	—	111	8.62	20.6
			4			81.7	—	47	61.2	6.29	15.6
			5			85.0	14,800	—	39.5	2.48	25.6
			6			85.0	—	94	64.5	3.68	28.1
			7			82.7	29,600	—	—[c]	—[c]	18.1
			8			82.7	—	188	18.9	1.09	27.8
			9			84.5	59,100	—	11.2	1.14	15.6
			10			84.5	—	376	13.5	2.61	8.4
			11			84.3	88,600	—	6.6	1.41	7.5
			12			84.3	—	565	1.6	0.20	11.9
			13			84.6	7,390	—	31.0	2.93	16.9
			14			—	—	47	—[d]	—[d]	—[d]
			15			84.6	14,800	—	—[a]	—[a]	18.1
			16	↓	↓	84.6	—	94	—[a]	—[a]	15.6
VI	66	4/13/57	1	1,400	0.5:1	85	—	—	123.8	9.30	21.3
		↓	2	↓	↓	↓	—	—	171.8	9.94	27.7
		6/18/57	3				—	—	170.3	7.37	37.0
			4				—	—	220.4	7.10	49.7
			5				12,400	—	33.6	3.11	17.3
			6				12,400	—	42.7	3.49	19.6
			7				12,400	—	49.8	3.57	22.3
			8				12,400	—	31.5	3.15	16.0
			9				—	65.4	38.9	2.52	24.7
			10				—	65.4	52.5	2.07	40.7
			11				—	65.4	35.4	1.28	44.3
			12				—	65.4	28.8	1.67	27.7
			13				—	—	67.3	—[b]	—[b]
			14				—	—	18.0	1.52	19.0
			15				12,400	—	18.4	0.90	32.7
			16	↓			—	65.4	35.0	2.27	24.7
			17	400			11,720	—	0.1	0.00	32.7
			18	400	↓	↓	—	50	2.7	0.14	31.7
VII	21	7/1/57	1	1,556	1.2:1	87	—	—	0.3	0.02	30.7
		↓	2	↓	↓	↓	—	—	0.4	0.02	31.8
		7/22/57	3				—	—	21.8	1.06	32.9
			4				75,000[e]	—	0.1	0.00	42.9
			5				15,800[f]	—	142.4	20.23	11.2
			6				15,800[f]	—	98.0	4.05	38.8
			7				15,800[f]	—	117.8	5.42	34.8
			8				15,800[f]	—	0.1	0.00	75.7
							75,000[e]	—	—	—	—
			9				—	80.4	102.8	4.65	35.3
			10				—	80.4	0.3	0.01	39.1
			11				—	80.4	—[c]	0.02	31.9
			12	↓			75,000[e]	80.4	2.0	0.42	74.7
			13	1,400			—	—	0.7	—[b]	—[b]
			14	1,400			—	—	108.2	8.72	19.9
			15	1,556			15,800[f]	—	0.3	0.02	30.8
			16	1,556	↓	↓	—	80.4	6.5	0.82	12.7

[a] Leaks found in gas system.
[b] Solids determination, no volatile matter reduction.
[c] No gas produced.
[d] Pump line broke, spilling contents.
[e] Glucose.
[f] KH_2PO_4.

TABLE III.—*Continued*

Run	Period (days)	Date	Dig. No.	Experimental Conditions					Total Gas Prod.		Red. Vol. Matter (%)
				Sludge Vol. (ml)	Sludge Mixture	Inc. Temp. (°F)	Conc. KH_2PO_4 (ppm)	Conc. P^{32} (mc/l)	Ml per gm V.M. Added	Cu ft per lb V.M. Destroyed	
VIII	42	7/23/57	1	1,910	1.5:1	85	—	—	16.76	0.71	37.68
		↓	2	↓	↓	↓	—	—	31.9	1.078	47.25
		9/2/57	3				—	—	35.5	1.727	32.72
			4				30,900[e]	—	8.44	0.521	25.86
			5				6,470[f]	—	24.3	—[b]	—[b]
			6				6,470[f]	—	70.13	4.804	23.32
			7				6,470[f]	—	44.58	4.503	15.80
			8				6,470[f]	—	7.25	—[b]	—[b]
							30,900[e]	—	—	—	—
			9				—	11.6	31.70	1.185	42.72
			10				—	11.6	13.09	0.478	43.80
			11				—	11.6	6.02	0.568	17.41
			12				30,900[e]	11.6	8.62	0.351	39.20
			13	1,750	1.9:1		—	—	6.75	—[b]	—[b]
			14	1,750	1.9:1		—	—	41.87	1.376	48.72
			15	1,910	1.5:1		6,470	—	8.72	—[b]	—[b]
			16	1,910	1.5:1	↓	—	11.6	6.42	0.764	12.53

[a] Leaks found in gas system.
[b] Solids determination, no volatile matter reduction.
[c] No gas produced.
[d] Pump line broke, spilling contents.
[e] Glucose.
[f] KH_2PO_4.

Experimentation was performed with samples composed of 800 to 1,600 ml of sludge, depending on the concentration of radioactivity to be studied. To eliminate one variable and to strengthen the results, all digesters were immersed in the same temperature bath beginning with Run VI; because water bath temperature was continuously recorded, any variation in temperature would affect all digesters identically. The incubation temperatures for each run were chosen just below or within the optimum mesophilic range, which has been variously reported (36)(37)(46) to extend from 81°F to 98°F. A complete schedule of the experimental conditions for all laboratory runs with P^{32}, including gas production and volatile matter reduction, is shown in Table III. Because most of the gases of decomposition are partially soluble in water, especially carbon dioxide, equilibrium saturation of CO_2 was maintained and 1 ml of phosphoric acid was added to the water in each gas collector to reduce experimental error during quantitative gas measurement.

Gas production from all digesters was observed daily and all gas volumes were corrected to standard conditions (0°C and 760 mm Hg). This data reduction was necessary to be able to compare cumulative gas volumes and to plot cumulative gas production curves.

The composite of reactions involved in the anaerobic stabilization of the complex organic matter in well-seeded sludge may be characterized by a first-order reaction. The application of this type of equation is based on the assumption that the reaction velocity k is a function of the organic matter remaining to be decomposed:

$$\frac{dy}{dt} = k(G - y) \quad \ldots\ldots\ldots (3)$$

in which

y = the amount of gas produced in time t;

G = total amount of gas generated during digestion;
k = reaction velocity constant; and
t = time, in days.

Integrating the differential form between the limits of $t = 0$ and $t = t$, the equation becomes:

$$y = G(1 - 10^{-kt}) \quad \ldots\ldots (4)$$

In general, Eq. 4 describes anaerobic digestion adequately. If the amount of seeding material is small compared to the raw solids concentration, an S-shaped, or autocatalytic, gas production curve is obtained. After an initial lag phase the rate of gas production increases until about one-half of the total amount of gas is generated. The rate of gas production then decreases.

To formulate the cumulative gas production where a seeding lag is present, Fair and Moore (32) used the autocatalytic equation containing two reaction velocity constants as shown by the differential form:

$$\frac{dy}{dt} = k_1(G - y)\, y + k_2(G - y) \quad \ldots (5)$$

As an alternate approach, they separated the S-curve into two parts; the first to follow an exponential equation, and the second to follow a first-order equation. To formulate sludge digestion, autocatalytic reactions are often treated by neglecting the lower bend of the S-curve and fitting the upper part of the curve as a first-order reaction starting at some time later than $t = 0$. This is equivalent to extrapolating the origin of the curve to the end of the seeding lag at $t = 0$. The interval between the origin and the extrapolated point is called the lag or time lag. Thomas (47) formulated the first-order reaction to include a time lag by the following expression:

$$y = G(1 - 10^{-k(t-t_0)}) = G(1 - C\,10^{-kt}) \quad \ldots (6)$$

where t_0 = time lag and $t_0 = \frac{1}{k} \log C$.

During most of the experimental runs described, only the second part of the S-curve applied because the time lag and the exponential phase did not develop. The reason is that the relative amount of seeding material was large as compared to the amount of digestible matter added.

The value of the reaction velocity constant found by Fair and Moore (32) for the second part of the curve was $k_2 = 0.073$ (base 10) at 95°F, which is comparable to the value of $k = 0.109$ as obtained in this study. From a recent study, Schulze (48) reported an average k-value of 0.061 without any appreciable lag. The main object in fitting sludge digestion data to a first-order reaction constant, k, and ultimate gas production, G, was to obtain valid parameters with which to compare the influence of radioactive materials on sludge digestion and which could be subjected to statistical analysis to test the significance of any real differences from a large number of observations from which an interpretation of effects could be made.

To insure the validity of any conclusions based on statistical analysis, it was necessary to include an equal number of control digesters to distinguish any effect due to chemical toxicity which might result from the radioactive waste. During the experiments with P^{32}, the same concentrations of potassium di-hydrogen orthophosphate (KH_2PO_4) were added to insure valid controls.

It may be observed from Table III that the equivalent concentration of KH_2PO_4 for control digesters varied, even though the levels of P^{32} activity between successive runs remained the same. This variation was due to changes in specific activity (mc/g) between radiophosphorus shipments from Oak Ridge National Laboratory. The estimated yield from a standard reactor unit containing 31.0 g of KH_2PO_4 is 200 mc of P^{32} after 28 days of irradiation (49). With higher

TABLE IV.—Determinations of pH in Sludge with Increasing Concentrations of KH_2PO_4

Nominal Conc. of P^{32} for Run III (mc/l)	KH_2PO_4 Required* (g/700 ml)	KH_2PO_4 Required for Test with 50 ml Sludge (g/50 ml)	Conc. of KH_2PO_4 (ppm)	Measured pH Values	
				Test 1	Test 2
0	0	0	0	6.35	6.4
50	10	0.7	14,280	5.80	6.1
100	20	1.4	28,560	5.82	5.90
200	40	2.8	57,120	5.59	5.75
400	80	5.7	114,240	5.2	5.4
800	160	11.4	228,480	5.1	5.1

* An original yield of 125 mc/31.0 g of KH_2PO_4 was assumed. These values were then corrected to allow for a time lapse of almost three days between ORNL assay and dosing of digester, equivalent to a decay of 0.2 $T_{\frac{1}{2}}$ so that only 88 per cent of the original activity was left. This increased the salt concentration relative to the activity.

flux densities (5×10^{11} to 10^{13} neutrons/sq cm/sec) in the Oak Ridge graphite reactor during the irradiation period, as much as 125 mc of activity per reactor unit in one week is possible. Therefore, depending on the period available for irradiation and flux setting, besides location of the target material and other substances in the immediate vicinity in the reactor, different specific activities were obtained. Because the levels of radiophosphorus in the digesters were based on total activity, the equivalent concentration of KH_2PO_4 added to the controls had to be varied with each run. The most economical way in which P^{32} could be shipped was in the carrier salt form. Preliminary experiments were conducted to establish the approximate pH values that could be expected due to the high concentrations of KH_2PO_4, which would have to be added to the control digesters. Table IV shows that with concentrations as high as 228,500 ppm (22.85 per cent), the pH value will drop to 5.1 due to the salt. These results were obtained with duplicate sets of 50-ml samples of the same sludge mixture as used during Run III.

Experimental Results with P^{32}

Gas Production

Representative curves of the results of cumulative gas production in milliliters per gram of volatile solids added are presented in Figures 1 and 2. To present similar curves for all other experimental digesters with activity concentrations within the same range would be impractical. Therefore, only typical curves are presented.

Figure 1 shows the effect of increasing concentrations from 50 mc/l to 800 mc/l of radiophosphorus (as KH_2PO_4) on gas production. These curves are composites from Runs III and V. Both runs are comparable because approximately the same concentrations of P^{32} were studied and similar temperatures were maintained. In Figure 2 the effect of increasing concentrations from 0.74 to 5.9 per cent of stable KH_2PO_4, added to the control digesters during Run V, is shown. These concentrations were equivalent to the P^{32} activity levels between 50 mc/l and 400 mc/l. It may be noted that beginning with 50 mc/l of P^{32} a considerable reduction of gas production appeared, as compared with the results from plain sludge digesters. This difference also holds true for the control digesters to which the equivalent concentrations of KH_2PO_4 were added. From data not shown in these figures, gas production did not appear to be affected at concentrations of 1.0 mc/l (Run II), but some reduction was noted with 12 mc/l of P^{32} (Run VIII).

As the concentration of P^{32} was in-

creased from 100 mc/l to 800 mc/l, correspondingly increasing tendencies of restraint and finally destruction of digestion were noted. As may be seen in Figure 1, the gas production rate dropped to zero after the fifth day at the 100-mc/l level, and after the third and fourth day at the 400-mc/l and 800-mc/ level of P^{32}. Before concluding that this effect is due to P^{32} alone, it is necessary to examine Figure 2, representing the gas production curves for the control digesters. Gas production was inhibited at a concentration of 7,390 ppm KH_2PO_4, analogous to the 50-mc/l level of P^{32}. The rate of gas production dropped to zero after the third day for the units with concentrations of 14,780 and 59,120 ppm KH_2PO_4, equivalent to 100 mc/l and 400 mc/l of P^{32}. An earlier experiment (Run III) had brought similar results. Cumulative gas production curves obtained with other concentrations of salt confirm these results, but are not shown in Figure 2 to preserve clarity.

Because it is known that a low pH (5.1) is detrimental to microbiological organisms, the breakdown of digestion may be ascribed to the chemical effects of KH_2PO_4 equivalent to the P^{32}, rather than to radiological effects.

It may be seen from Table III that the efficiency of gas production expressed as ml/g of volatile matter added and cu ft/lb of volatile matter destroyed is similarly affected. With increasing concentrations of radioactivity or KH_2PO_4, the gas produc-

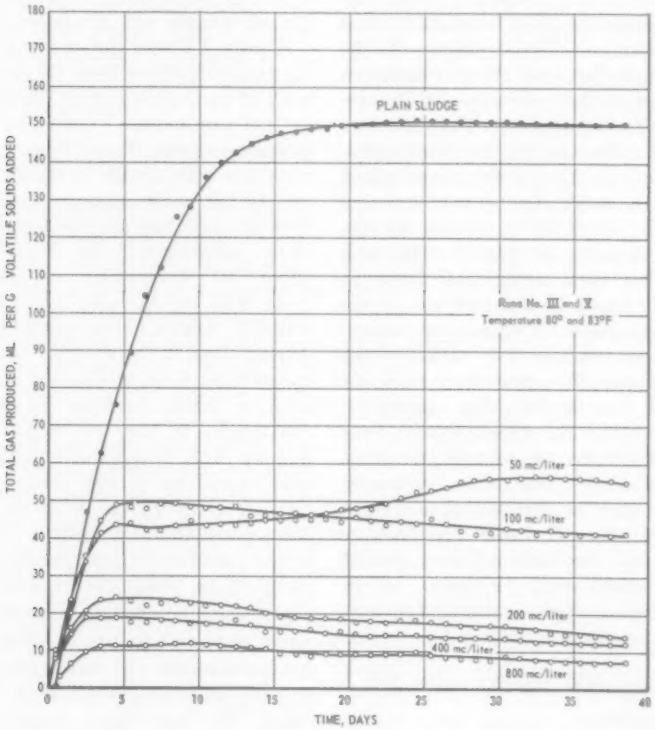


FIGURE 1.—Cumulative gas production with various concentrations of P^{32} (as KH_2PO_4).

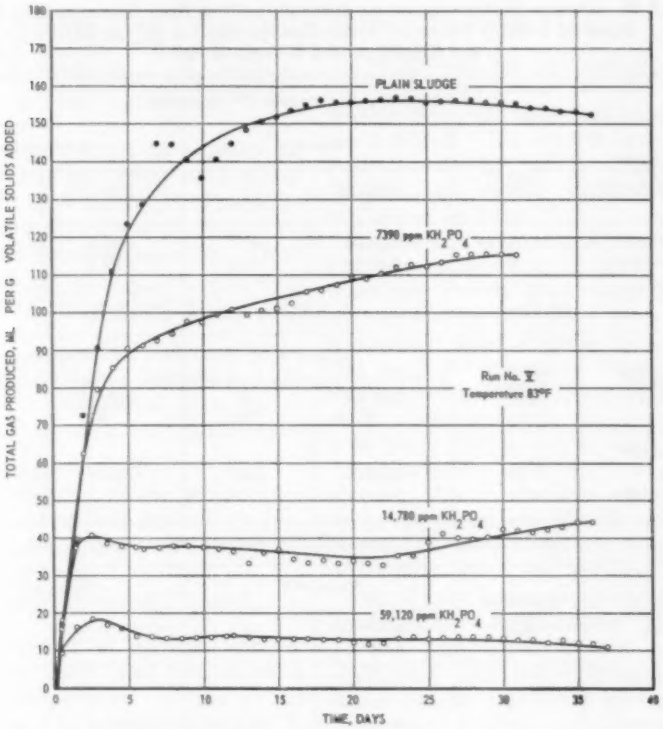


FIGURE 2.—Cumulative gas production with various concentrations of KH_2PO_4 (control).

tion efficiencies decrease rapidly. Van Kleeck (50) points out that under favorable conditions of digestion, gas production should be 11 to 15 cu ft/lb of volatile matter destroyed. This value, established from the operation of continuously fed digesters, is considerably higher than that found for most of the plain digesters in Runs I through VIII, but even considerably lower values were found for concentration of P^{32} over 50 mc/l and equivalent KH_2PO_4 concentrations of 14,500 ppm and more. The reduction of volatile matter, as may be seen in Table III, followed a similar pattern, but due to the relatively large variation in the solids determinations interpretation is limited by the poor confidence in these results.

Reaction Velocity Constant

Reaction velocity constants were computed from the cumulative gas production curves for all the runs as far as data were available. As has already been pointed out, it is more difficult to obtain sufficient data for the purpose of computing a velocity constant for anaerobic digestion than for aerobic stabilization. The number of days of observation necessary to fit a first-order type of curve is increased and the interpretation of the time lag is often poorly defined. Since gas production was severely reduced and in most cases absent after the first few days with P^{32} activities over 100 mc/l and with equivalent concentrations of KH_2PO_4, no k-values were computed for the short time intervals.

TABLE V.—Average Differences and the Probability (P) of Their Occurrences by Chance Alone for k and G Values at Various Concentrations of P^{32} (as KH_2PO_4) and KH_2PO_4 Added to Plain Sludge

(a) Comparing Plain and P^{32} Sludges

Plain Sludge vs. P^{32} (mc/l)	Number of Digester Pairs	Values of k		Values of G	
		$\bar{d}=\frac{\Sigma(k_c-k_A)}{n}$	$\frac{P}{(\%)}$	$\bar{d}=\frac{\Sigma(G_c-G_A)}{n}$	$\frac{P}{(\%)}$
1.0 to 100	17	+0.0174	69.7	+45.5	3.3
50 to 100	6	+0.0518	70.4	+88.1	4.0

(b) Comparing Plain and KH_2PO_4 Sludge (Control)

Plain Sludge vs. KH_2PO_4 (ppm)	Number of Digester Pairs	Values of k		Values of G	
		$\bar{d}=\frac{\Sigma(k_c-k_s)}{n}$	$\frac{P}{(\%)}$	$\bar{d}=\frac{\Sigma(G_c-G_s)}{n}$	$\frac{P}{(\%)}$
6.25×10^3 to 28.6×10^3	13	−0.0098	86.2	+61.8	4.0

(c) Comparing P^{32} and KH_2PO_4 Sludge (Control)

P^{32} (mc/l) vs. KH_2PO_4 (ppm)	Number of Digester Pairs	Values of k		Values of G	
		$\bar{d}=\frac{\Sigma(k_s-k_A)}{n}$	$\frac{P}{(\%)}$	$\bar{d}=\frac{\Sigma(G_s-G_A)}{n}$	$\frac{P}{(\%)}$
10 to 100 *vs* 6.25×10^3 to 28.6×10^3	11	+0.0169	78.1	+21.0	11.2

It was decided that a k-value based on 30 days of data was most satisfactory for a comparison of all other digesters in all the runs, which varied up to 95 days in length. The results of statistically evaluating the significance of any effects due to the presence of radioactivity in concentrations from 1 to 100 mc/l for various sludge mixtures and temperatures is shown in Table V. The comparison in each case was made between k-values for plain digesters vs. k-values for digesters with P^{32} at each level of activity. Students' t-distribution and the "t" test for significance were used (51).

As in many cases where biological reactions are involved, the test for significance is based on the 95 per cent confidence limits. Thus, with the use of the t-distribution, an average of the differences between plain and radioactive sludge is considered significant only when such stated difference can be expected to occur by chance alone less than 5 per cent of the time.

Table V shows no significant difference on the reaction rate of anaerobic digestion up to 100 mc/l. If an analysis comparing k-values could have included those obtained from sludges with activities exceeding 100 mc/l, it is probable that a significant reduction in the gas production rate would have been found. This is apparent from Figure 1 if the first 15 days are compared. A similar effect, however, would also be noted if a comparison were made between plain sludges and those containing an equivalent concen-

tration of KH_2PO_4. The results from a statistical analysis of those digesters with up to 28,600 ppm salt (Dig. 5, Run III) are also included in Table V.

In another attempt to examine if there was any real effect on k-values due to P^{32} (up to 100 mc/l), a multiple correlation analysis was performed by means of a high-speed computer. From a total of 70 values, the following regression equation was found:

$$k = -0.14 + 0.0032\,T - 0.0071\,M - 0.000007\,S_c + 0.00032\,P_c \quad (7)$$

in which

T = temperature, °F;
M = proportion of sludge mixture, based on fresh solids;
S_c = concentration of KH_2PO_4, ppm; and
P_c = concentration of P^{32}, mc/l.

The coefficient of multiple correlation, R, was found to be 0.26, which is highly non-significant. If the second term of Eq. 7 is multiplied by 100°F, a value of 0.32 for correlation of temperature with k-values is obtained which is still not significant. The data, therefore, do not support the hypothesis that k depends (linearly) on any or all the factors measured. Further, the variation in k is not appreciably diminished by taking out that portion of the variance due to (linear) effects of the other factors. One should be cautious in concluding that k is not influenced by any (or some) of these factors measured. It is quite possible that if all the experimental data could have been taken into account, including k-values approaching zero for all digesters with activities above 100 mc/l, a more significant correlation would have been found. The present analysis is biased by the complete absence of any values with the highest concentrations of P^{32} and KH_2PO_4 used in these studies.

Ultimate Gas Produced

The ultimate gas volumes, G, which could be calculated by the slope method were also subjected to statistical analysis. The results from comparing between plain, radioactive sludges, and sludges containing salt are shown in Table V.

Significant reductions of the ultimate gas production (ml/g) were found when the results from plain sludge digesters were compared with those containing activity levels from 1 to 100 mc/l P^{32} using the t-test. The average reduction of G-values was 46 ml/g when all levels were compared with plain sludge and 88 ml/g when only the higher levels of P^{32} were considered. These reductions were found to be significant at the 95 per cent probability level. Equally significant differences would be expected if G-values for the higher levels of P^{32} were available for t-test analysis. A comparison with digesters that received equivalent salt concentrations produced equally significant results.

It would appear that since no real effect due to P^{32} on k-values was observed, the rate of organic matter breakdown as characterized by gas production (as a result of the activities of microorganisms and enzyme systems) was not changed. However, since G represents total amount of gas generated and the rate of breakdown seems unaffected, the total organic matter available or accessible to the organisms for decomposition was reduced. No bacteriological studies were carried out, therefore further interpretation as to the possible mechanism responsible cannot be made.

Volatile Acids and pH

It is of interest to note that whenever sludge digestion was inhibited, either due to radioactivity or salt concentrations, the levels of volatile acids concentration at the end of the digestion period were above 1,500 to 2,000

ppm. Sludge which had proceeded through normal digestion contained not over 500 to 1,000 ppm, but some poorly digested samples tested up to 7,000 ppm of volatile acids. These observations were in full agreement with operating experience as well as accepted theory (34)(35).

In accordance with the other observations reported, it was not surprising to find that each digester containing an activity above 50 mc/l of P^{32}, or equivalent salt, reacted abnormally to pH changes. After the initial intensive acids production phase when the pH value of the plain sludge started to rise, the pH for the digesters containing the salt and the P^{32} would definitely lag behind, as shown in Figures 3 and 4. This effect was particularly noticeable at the higher concentrations of salt and P^{32} above 200 mc/l, when the pH never rose to even near 7.0 but remained at the initial values, ranging from 5.0 to 6.0, while the plain digesters rose to 7.0 and above.

At 800 mc/l, the concentration of KH_2PO_4 in the sludge was 20 per cent. At this concentration (approximately 2M KH_2PO_4) strong but low pH buffer tendencies are exerted by the phosphates. Even if the organisms survived in this acid medium, it would be difficult to bring the pH to 7, but it is likely that the microbiological flora and fauna, normally responsible for establishing a buffered sludge, could not continue to exist.

Influence on Redox Potential and Liquid Conductivity

To obtain continuous redox potentials, conductivity, and pH measurements, which were recorded, the sludge was kept moving through all sensing elements. As pointed out earlier, digesters 13 through 16 were so designed that the sludge could be recirculated

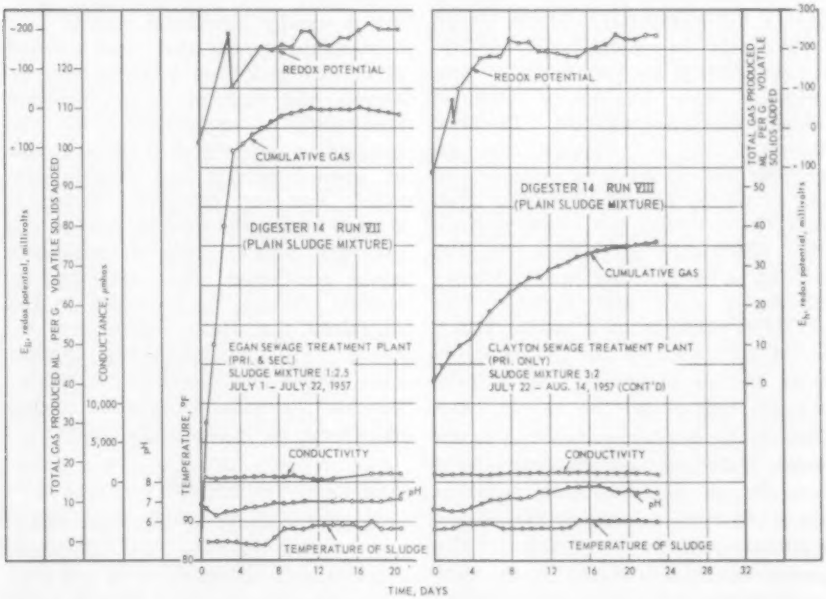


FIGURE 3.—Cumulative gas production, potentials, conductivity, pH, and temperature measured during digestion of plain sludge mixture.

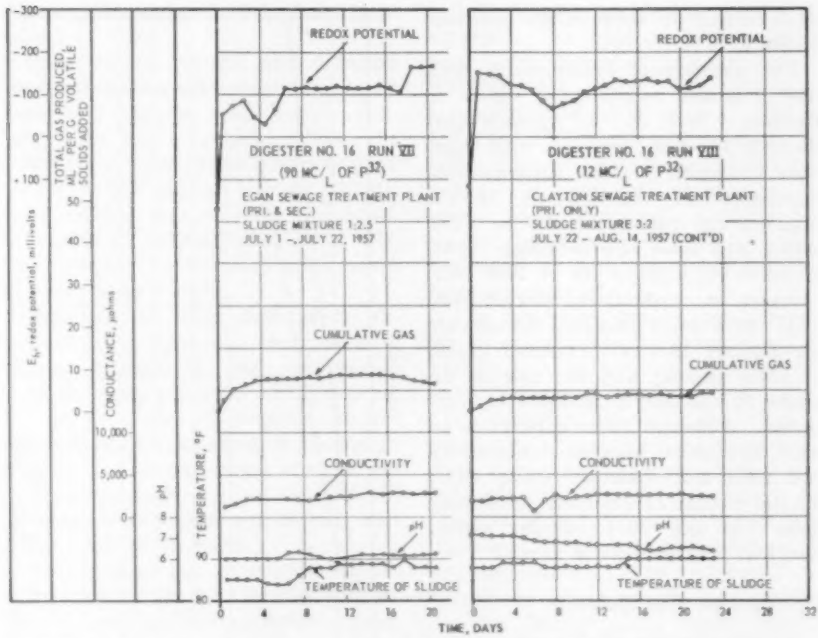


FIGURE 4.—Cumulative gas production, potentials, conductivity, pH, and temperature measured during digestion of sludge containing radiophosphorus.

on a time-programmed basis and therefore cannot be directly compared with batch digesters 1 through 12. Figures 3 and 4 show the results obtained from two digesters during both Runs VII and VIII. Run VIII was a continuation of Run VII to investigate the degree to which anaerobic digestion could assimilate radioactivity. At the end of Run VII, 800 ml of the sludge mixture were withdrawn and 1,150 ml of a new sludge mixture were added, the resulting mixture constituting Run VIII. At the beginning of Run VIII the radioactivity had decayed to 12 mc/ml as calculated from the original Oak Ridge National Laboratory assay.

Total gas production for digester 14 (plain sludge) reached 110 ml/g of volatile matter added in Run VII and about 75 ml/g of volatile matter in Run VIII, as shown in Figure 3. However, digester 16 (90 mc/ml of P^{32}) produced only 10 ml/g of volatile matter added in Run VII and only 5 ml/g of volatile matter in Run VIII, as shown in Figure 4. These results show a distinct inhibition of the gas production efficiency in the presence of P^{32} (as KH_2PO_4), which was quite similar for digester 15 (6,500 ppm KH_2PO_4), not shown.

During both Runs VII and VIII it is significant that the oxidation-reduction potential for digester 14 reached a value of -200 mv after a period of about one week, whereas the potential for digester 16 remained established at about -100 mv for three weeks. It was recently shown (42) that when complete anaerobic conditions become established in a digester the potential drops to -350 to -450 mv and that values of a lesser negative potential indicate poor anaerobiosis. The results from continuous ORP measurements, therefore, bear out the inhibition of anaerobic digestion and

tend further to support the previous findings.

The increase of conductivity with time was also recorded, as shown in Figures 3 and 4. It appears that changes of this variable with time were too small to lend themselves to interpretation. In digester 14 the conductivity rose from 800 to 1,250 μmhos and from approximately 2,000 to 3,500 for digester 16 in Run VII. Changes in conductivity during Run VIII were even smaller, the change for digester 14 was very small (1,000 to 1,300 μmhos) and the rise in digester 16 was only from 2,000 to 2,500 μmhos. Although there appears to be some correlation between conductivity and total and dissolved solids (39), the net change of conductivity during Runs VII and VIII (similar sludge samples) was unusually small.

Influence on Gas Quality

An investigation of the composition of sludge gas was considered essential to a study of the effects of P^{32} on anaerobic digestion. It was necessary to develop methods that would quantitatively analyze the various components in sludge gas on a routine basis. Because no chromatographic gas analyzer was commercially available at the time these investigations were started, such a device was developed during the course of these studies. Its design and operation have been reported elsewhere (43)(44).

From the standpoint of plant design and operation, especially if the gas is used to heat digesters, to drive compressors in activated sludge plants, or for electric power generation, it is necessary to establish if the methane concentration (net fuel value) of the gas is affected by radioactive wastes. It is also necessary to determine if any of the gases of decomposition contain radioactivity that could cause an environmental hazard. Chromatographic analysis of the gas prior to radioassay would permit identification

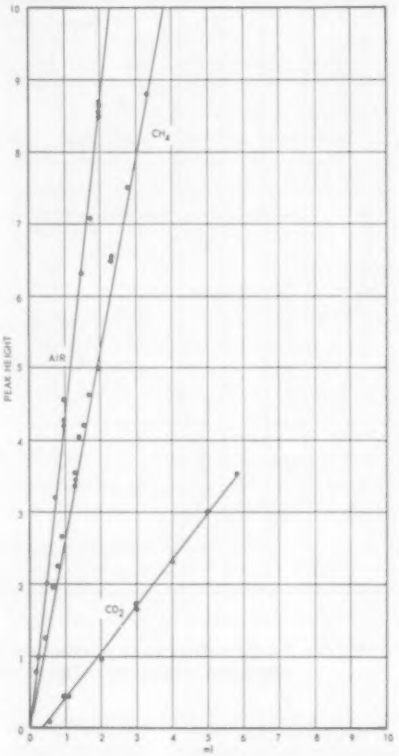


FIGURE 5.—Calibration curves for air, CH_4, and CO_2; for use with Figure 6.

of the gaseous component(s) responsible for atmospheric pollution and indicate which component would have to be scrubbed from the gas stream prior to combustion or release.

To determine the gross beta and gamma activity in the gas phase, a number of gas samples were counted under an end-window G-M tube sealed in a beaker, as well as in a Marinelli beaker with a self-quenching dip counter.* No appreciable activity above background was detected in the digester gas from any of the experiments.

Significant changes in gas composition were noted from digesters to

* Model D–52, Nuclear-Chicago (silver cathode and 35-mg/sq cm window thickness).

which P^{32} and KH_2PO_4 had been added.

Quantitative results are obtained from calibration curves, established by analyzing samples with known mixtures. It has been found that the quantity of gas is linear with peak height. Calibration curves for air, methane, and carbon dioxide are shown in Figure 5. A small quantity of CO_2 was absorbed by the silica gel column at room temperature.

Gas samples from each of 16 digesters were analyzed every day to follow changes in gas composition with digestion progress. A typical set of results from the chromatographic analysis of 12 digesters is shown in Figure 6. The separation of these gas components was obtained with a 28–48 mesh, 4.5-ft silica gel column, and a flow rate of 75 ml/min.

The digester gas analyses from the third day of Run VIII showed that the methane concentration when compared with the plain sludge gas was reduced from 60 to 40 per cent in the presence of 12 mc/l of P^{32} and 6,500 ppm of KH_2PO_4, accompanied by a simultaneous increase in CO_2 concentration from 40 to 59 per cent. From Table VI it appears that both methane reduction and carbon dioxide increase are essentially the same for digesters containing P^{32} and the control (KH_2PO_4). Slightly lower CH_4 concentrations and slightly greater CO_2 increases for the control digesters could be due to experimental error, although excellent reproducibility between digesters of one kind should be noted, which provides substantiating evidence of good sludge sampling technique between digesters.

In this experimental run digesters 4, 8, and 12 were charged with a 3.1 per cent d-glucose solution and seeded with the same sludge mixture as the other digesters of Run VIII (see Table III). The purpose in using glucose was to experiment with a synthetic sludge composition from which a known gas composition could be expected. To digester 8 an equivalent concentration (6,470 ppm) of KH_2PO_4 was added, to digester 12 a concentration of 12 mc/l of P^{32} (as KH_2PO_4). The chromatographic results of gas analyses from digesters 4, 8, and 12 deviate considerably from all others when compared in Table VI, showing practically no methane in the gas, more air, and considerably higher concentrations of CO_2.

The results of similar gas analyses for 28 days of Run VIII are shown in Figure 7, from which the glucose experiments were excluded. Plotting CO_2 concentration as a function of time, it is apparent that for those digesters in which gas production was reduced, the CO_2 content sharply increased—although toward the end of the digestion period this difference is less pronounced. The results are in agreement with a recent study by Miller and Barron (52), whose records indicate that during normal digester operation a gas with 31 to 35 per cent CO_2 content is produced. The deviations of CO_2 content between digesters containing P^{32} (as KH_2PO_4) and their controls usually were only 1 to 2 per

TABLE VI.—Qualitative Gas Analyses from 16 Digesters Run VIII* (P^{32})

Dig. No.	Conc. of KH_2PO_4 (ppm)	Conc. of P^{32} (as KH_2PO_4) (mc/l)	Percentage by Volume		
			Air	CH_4	CO_2
1	Plain sludge	—	0.3	60.1	39.6
2	Plain sludge	—	0.6	59.0	40.4
3	Plain sludge	—	0.1	58.8	41.1
4	Plain sludge†	—	4.1	1.8	94.1
5	6,470	—	0.4	40.0	59.6
6	6,470	—	0.3	40.2	59.5
7	6,470	—	0.6	39.7	59.7
8	6,470†	—	2.0	0.3	97.7
9	6,470	12	0.6	41.6	57.8
10	6,470	12	0.3	41.3	58.4
11	6,470	12	0.2	40.3	59.5
12	6,470†	12	0.3	0.6	99.1

* Analyses from third day of Run VIII.

† Substrate consisted of 30,900 ppm glucose, seeded with digesting sludge.

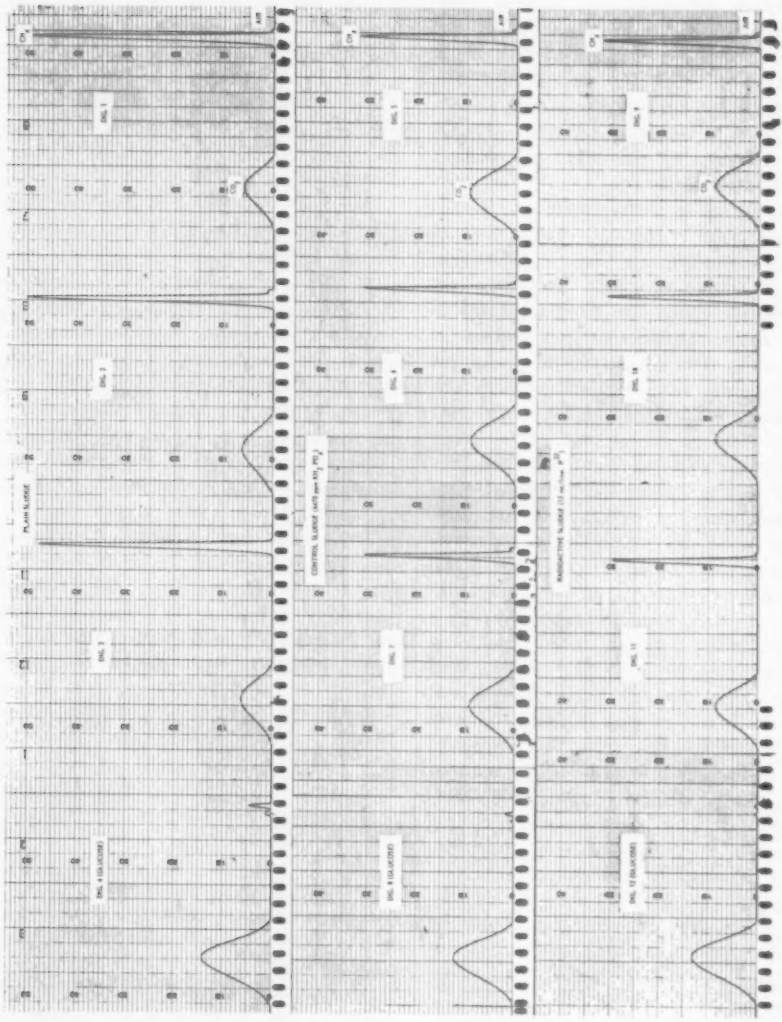


FIGURE 6.—Gas chromatographic analysis of sludge gases, Run VIII, P^{32} (third day, July 25, 1957); sample size 3 ml each; other data as in Figure 5.

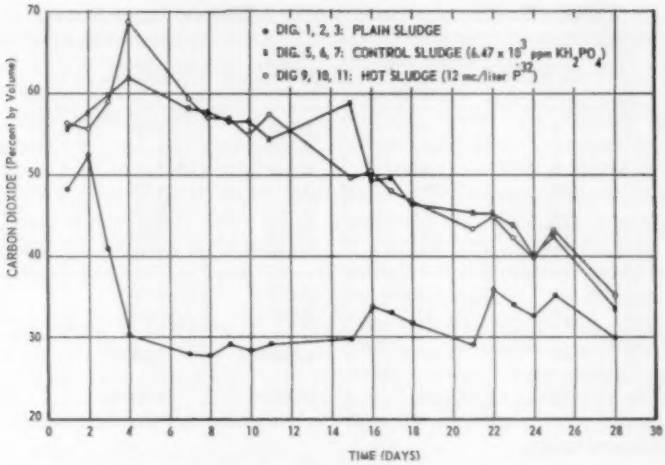


FIGURE 7.—Digester gas composition, Run VIII, P^{32}.

cent and may be attributed to experimental error.

Distribution between Solid and Liquid Phases

The purpose of these studies included the determination of concentration of radioactivity in the solid and the liquid phase for the safety of plant personnel and the establishment of disposal limits. The liquid phase (overflow and underflow) is practically always returned to the treatment process and allowed to go to the stream after secondary treatment. The solid phase is removed from the digester and retained on sludge drying beds for additional drainage and evaporation, producing a dried sludge cake similar to humus in appearance. Final disposition is either as a soil lightening material or as a fertilizer when admixed with nutrients. Therefore, both liquid and solid phases, unless carefully monitored, may in time contribute to an increasing background of radioactivity. It is important to define the terms solid and liquid phase as applied to the distribution of radioactivity reported in this paper. This requires a brief explanation of salient features of the experimental technique.

Two procedures were used for solid-liquid determinations: (a) counting the digested mixture and its liquid portion separately with a Marinelli beaker and a dip counter, and (b) counting centrifugally-separated liquid and solid samples prepared by the evaporation technique. To measure the activities and distributions of radioactivity the samples were withdrawn after the period of digestion and analyzed by both of these techniques. The evaporation technique produced the more reliable data, as determined from the variance and standard errors. Therefore, the data reported, unless otherwise noted, were obtained from evaporated samples.

The sample, upon removal from the digester, was allowed to stand and settle to form a clear supernatant. A sample of the liquid was removed, further clarified in a centrifuge at 4,500 rpm, and a 1-ml sample or less was pipetted on a previously weighed sample pan. The pan was dried under infrared heat, and sprayed with a plastic spray to set the sample and prevent contamination of the proportional gas flow counter.

The solid samples, after being obtained with a draft tube immersed in

TABLE VII.—Determination of Activity in Solid and Liquid Phases

Run	Dig. No.	Initl. Conc. of Activity (mc/l)	Solid Component, S (mc/g)	Liquid Component, L (mc/g)	$\frac{S}{L} \times 100$ (%)
III and IV	4	50	0.0385	0.297	13.0
	6	100	0.385	1.196	32.2
	8	200	0.606	1.418	42.7
	10	400	1.04	1.97	52.5
	12	800	1.38	2.34	58.9
	14*	50	0.274	1.29	21.3
	16*	200	0.525	1.44	36.4
V	4	19.25	0.178	2.17	8.2
	16*	41.5	0.429	2.02	21.2
VI	10	65.4	0.000853	0.00323	26.3
VII and VIII	16*	125	0.00036	0.00118	30.5

* Recirculated sludge.

the settled sludge, were also centrifuged. The supernatant liquid was wasted. A thin film of the solid remaining in the centrifuge tube was put on a previously weighed pan, dried under infrared heat, and the sample set with plastic spray. Both liquid and solid samples thus prepared were weighed to obtain the dried sample weight and the activity was determined in a gas flow proportional counter. Typical results of these determinations are summarized in Table VII.

For the P^{32} studies, a summary of the data of activities determined is shown in two graphs. Figure 8 represents a semi-logarithmic plot of the ratio of activity in the solid to the liquid, in millicuries per gram, against initial activity added. Although the ordinate represents a dimensionless

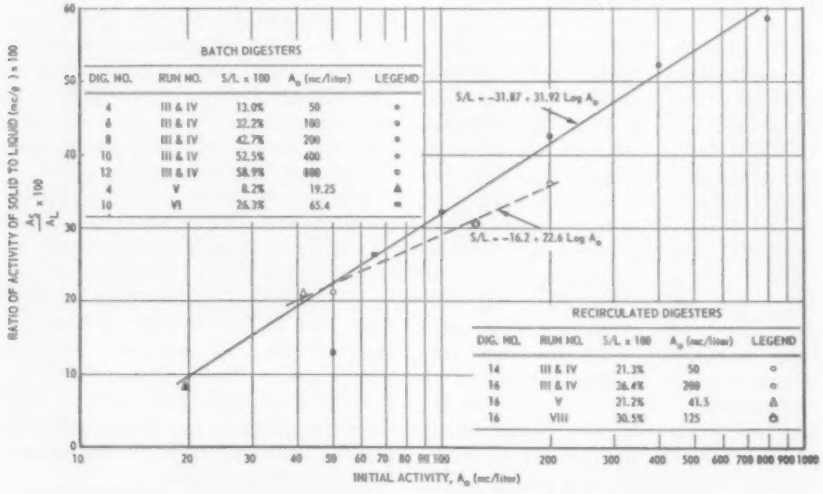

BATCH DIGESTERS
DIG. NO. | RUN NO. | S/L x 100 | A_o (mc/liter) | LEGEND
4 | III & IV | 13.0% | 50 | ○
6 | III & IV | 32.2% | 100 | ○
8 | III & IV | 42.7% | 200 | ○
10 | III & IV | 52.5% | 400 | ○
12 | III & IV | 58.9% | 800 | ○
4 | V | 8.2% | 19.25 | △
10 | VI | 26.3% | 65.4 | □
S/L = −31.87 + 31.92 Log A_o
S/L = −16.2 + 22.6 Log A_o
RECIRCULATED DIGESTERS
DIG. NO. | RUN NO. | S/L x 100 | A_o (mc/liter) | LEGEND
14 | III & IV | 21.3% | 50 | ○
16 | III & IV | 36.4% | 200 | ○
16 | V | 21.2% | 41.5 | △
16 | VIII | 30.5% | 125 | ◔
RATIO OF ACTIVITY OF SOLID TO LIQUID (mc/g) x 100
$\frac{A_S}{A_L} \times 100$
INITIAL ACTIVITY, A_o (mc/liter)
0
10
20
30
40
50
60
70
80
90
100
200
300
400
500
600
700
800
900
1000

FIGURE 8.—Distribution of activity with P^{32} (as KH_2PO_4) between solid and liquid components.

ratio, the units (mc/g) are shown to point out that the activities were determined on a unit weight basis. There appears to be a definite trend of increasing relative activity in the solid component with an increase of initial activity. The relationship is exponential and plots as a straight line on semi-logarithmic basis. The equation of best fit for this relation for P^{32} was found to be:

$$\frac{A_S}{A_L} = -31.87 + 31.92 \log A_0 \quad (8)$$

in which

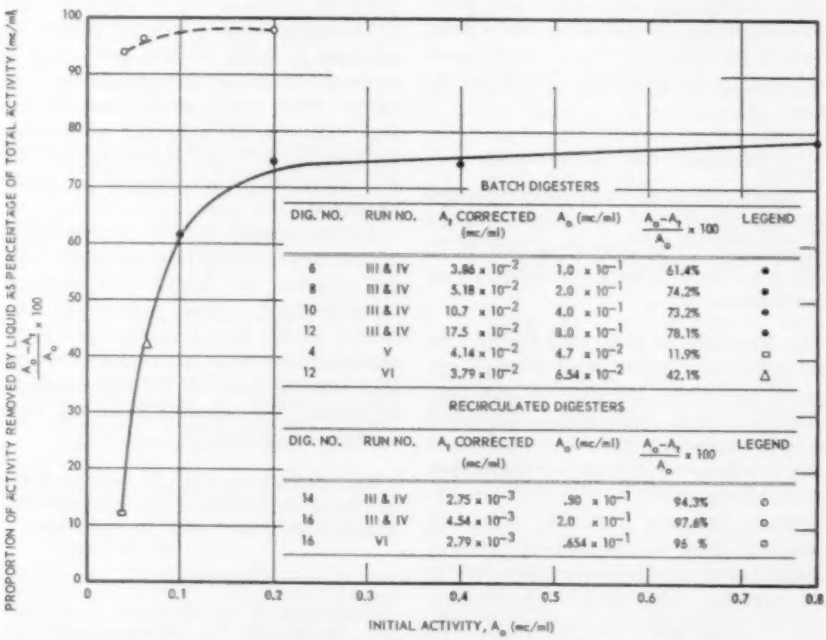
A_S = activity of solid phase, mc/g;

A_L = activity of liquid phase, mc/g; and

A_0 = initial activity of sludge mixture, mc/l.

Inasmuch as each run contained 12 digesters on a batch basis and 4 digesters in which the sludge was recirculated, more limited data on the effect of mixing were obtained. From Figure 8 it appears that relatively less activity concentrates in the solid as the initial activity is increased when the digester contents are mixed.

From a similar analysis of the results of these radioassays, another interesting relation has resulted. In Figure 9 the proportion of activity removed by the liquid phase, expressed as percentage of the initial activity (mc/ml) against initial activity was plotted. In contrast to Figure 8, the data presented here were obtained on a mc/ml basis. Actually, the proportion of activity removed is a dimensionless ratio but the unit (mc/ml) was inserted along the ordinate in Figure 9 to show that the activities were determined on a unit volume basis. This figure indicates concentrations of P^{32} in the liquid phase relative to the solid phase increasing from 12 to 78 per cent as the initial



BATCH DIGESTERS

DIG. NO.	RUN NO.	A_1 CORRECTED (mc/ml)	A_0 (mc/ml)	$\frac{A_0 - A_1}{A_0} \times 100$	LEGEND
6	III & IV	3.86×10^{-2}	1.0×10^{-1}	61.4%	●
8	III & IV	5.18×10^{-2}	2.0×10^{-1}	74.2%	●
10	III & IV	10.7×10^{-2}	4.0×10^{-1}	73.2%	●
12	III & IV	17.5×10^{-2}	8.0×10^{-1}	78.1%	●
4	V	4.14×10^{-2}	4.7×10^{-2}	11.9%	□
12	VI	3.79×10^{-2}	6.54×10^{-2}	42.1%	△

RECIRCULATED DIGESTERS

DIG. NO.	RUN NO.	A_1 CORRECTED (mc/ml)	A_0 (mc/ml)	$\frac{A_0 - A_1}{A_0} \times 100$	LEGEND
14	III & IV	2.75×10^{-3}	$.90 \times 10^{-1}$	94.3%	○
16	III & IV	4.54×10^{-3}	2.0×10^{-1}	97.6%	○
16	VI	2.79×10^{-3}	$.654 \times 10^{-1}$	96 %	○

FIGURE 9.—Proportion of activity removed with P^{32} (as KH_2PO_4).

activity increases from 50 to 800 mc/l. Higher concentrations in the liquid phase appear to be obtainable from digesters equipped with mixing apparatus. The initial activity, A_0, is based on total sludge mixture volume, but the final activity, A_f, represents the separated liquid phase of the sludge only. Thus, the percentage removal refers to the reduction of radioactivity from the initial concentration in mc/l of sludge mixture to the final digester effluent (both underflow and overflow) in mc/ml.

It should be pointed out that when the liquid phase was counted, only the dissolved solids remained with any of their associated activity; but when the solid material was counted, the activity in the liquid portion was also added to that of the solid activity during evaporation. In these results this had the effect of increasing the relative activity in the solid phase. To offset this experimental difficulty, the amount of liquid retained on the solid after centrifugal separation and prior to evaporation is probably lower than would be obtained from solid/liquid separation in prototype plant operation.

Summary and Conclusions

On the basis of these investigations on the effects of radioactive wastes containing P^{32} in concentrations up to 800 mc/l the following conclusions may be drawn:

1. Presence of P^{32} (as KH_2PO_4) in an initial concentration of 50 mc/l appears to reduce the rate of gas production from similarly prepared seeded mixtures without the equivalent salt solution. Although no significant probabilities could be obtained for differences between k-values, this may not have been due to lack of data for statistical analysis, but rather due to the complete inhibition of gas production at levels exceeding 400 mc/l. The ultimate gas production, G, was, however, significantly reduced in the presence of 50 mc/l or more P^{32} and with equivalent KH_2PO_4 concentrations. It is quite significant that the identical behavior was noted for the controls containing equivalent concentrations of stable KH_2PO_4 and it is therefore concluded that the effect noted is due to chemical toxicity to the microbiological environment, rather than a radiobiological effect caused by the P^{32}.

2. Supporting evidence of the effects between plain sludge, controls, and radioactive digesters, were obtained from the measurements of the volatile acids concentrations, the reduction of volatile matter, the pH, and continuously measured ORP.

3. It was demonstrated that continuous analysis by gas chromatography for methane and carbon dioxide is a practical tool and a sensitive indicator possible for routine plant operation. Without the presence of P^{32} (or the associated KH_2PO_4) the methane fraction was found to be approximately 60 per cent by volume in contrast to only 40 per cent with a corresponding increase in carbon dioxide. This would mean that the net fuel value in the presence of concentrations of P^{32} (as KH_2PO_4) or the salt alone would be reduced by about one-third.

4. The uptake of P^{32} by the solid component increases exponentially with an increase of initial radioactivity concentration. The percentage removed in the liquid phase appears to also increase with an increase of initial concentration of P^{32} and seems to be greater for digesters provided with mixing equipment.

Editor's Note:— Part II, containing the results of radioiodine (I^{131}) experimentation, will be published in an early issue.

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ACTIVATED CITRUS SLUDGE—VITAMIN CONTENT AND ANIMAL FEED POTENTIAL *

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Previous work done on both the laboratory scale (1) and pilot-plant scale (2) has shown that citrus waste waters can be readily treated by the activated sludge process. Preliminary work on the excess sludge from the treatment of citrus waste waters with an intermediate scale activated sludge plant (1) indicated that the sludge contained vitamins of the B group which would give it a value between that of dried whey and dried distillers' solubles if used as a chicken feed supplement. The excess sludge upon which these analyses were made was produced using a temporary arrangement which was set up strictly for sludge production. It was believed that the conditions for maximum vitamin production were not always present during that run and that a further study of the vitamin content should be made on excess sludge produced in a properly designed activated sludge system operating under normal conditions. Possible effects of varying amounts of inorganic nutrients on the vitamin content of the excess sludge was also felt necessary.

Apparatus and Procedure

The samples of excess sludge for the vitamin study were produced using the small, laboratory-scale, three-stage activated sludge system that was used in previous work (1). In that work it was found that the system could be operated without affecting the degree of treatment when the inorganic nutrients were eliminated. In starting the system for this vitamin study, an attempt was made to establish a new culture without the use of the inorganic nutrients. After three weeks of operation (a) the culture was slimy, (b) the sludge would not settle, (c) the effluent was cloudy, and (d) the treatment was poor. Rapid improvement was attained with additions of sodium nitrate and trisodium phosphate for N and P. After 10 days the sludge settled well and the effluent was clear and low in BOD.

Since it has been reported (3) that the addition of cobalt to a fermentation culture medium will increase the production of vitamin B_{12}, varying amounts of cobalt as cobaltous chloride were added to the raw waste during this study. The amounts used were varied along with the nitrogen and phosphate nutrients. Reported additions of N and P in this study do not include naturally occurring amounts from orange juice. Roberts and Gaddum (4) reported that orange juice contains an average of 0.030 per cent phosphorus (300 ppm) and 0.94 per cent organic nitrogen (940 ppm).

After a healthy culture had been established, the runs were started. On the first day of each calendar month the amounts of nutrients and cobalt to be used for that month's run were set. The system was allowed to run under these nutrient conditions for the first two weeks of the month with no sludge being withdrawn. During the last two weeks of the month sludge withdrawals were made from the bottom of the clarifier at the rate of one liter per day. It was calculated mathematically that at the end of the first two-week period

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TABLE I.—Reductions in Organic Solids and BOD Using Laboratory-Scale Activated Sludge System

Run No.	Raw Waste					Effluent		Reduction	
	$NaNO_3$ used (ppm N)	Na_2PO_4 used (ppm PO_4)	$CoCl_2$ used (ppm Co)	Organic solids (%)	BOD (ppm)	Organic solids (%)	BOD (ppm)	Organic solids (%)	BOD (%)
1	50	21.6	0	0.228	1,542	0.024	3.4	89.5	99.8
2	25	10	0	0.233	1,579	0.024	4.0	89.7	99.7
3	10	0	0	0.212	1,562	0.020	5.7	90.6	99.6
4	0	0	0	0.211	1,482	0.015	2.8	92.8	99.8
5	0	0	1	0.214	1,487	0.014	5.9	93.5	99.6
6	0	0	2	0.218	1,473	0.016	6.4	92.7	99.6
7	10	0	2	0.225	1,510	0.020	8.4	91.1	99.4
8	0	10	2	0.214	1,479	0.018	12.2	91.6	99.2
9	10	10	2	0.221	1,437	0.020	7.8	91.0	99.5
10	10	10	1	0.220	1,520	0.019	10.1	91.4	99.3
11	100	50	0	0.251	1,335	0.034	3.1	86.5	99.8
12	50	25	0	0.236	1,267	0.025	7.7	89.4	99.4
13	25	12.5	0	0.221	1,365	0.022	4.1	90.0	99.7
14	0	0	0	—	1,514	—	4.6	—	99.7
15	0	0	2	—	1,547	—	2.4	—	99.8

over 99.9 per cent of the liquid of the previous period had been washed through the system. It was concluded, therefore, that the properties of the sludge withdrawn during the second two-week period would not be noticeably influenced by the previous nutrient level.

For six of the first seven months of the study the withdrawn sludge was filtered each day and dried in an oven at 105°C for 24 hr. The other one of these samples was dried in a vacuum oven at 65°C for 24 hr but the oven proved to be mechanically faulty, thereby halting this method of drying. For the last eight months of the study the withdrawn sludge was filtered each day and stored in a refrigerator. At the conclusion of each run all of the sludge collected was dried on a drum dryer. Oven-dried sludge samples were ground in a mill and drum-dried samples were pulverized in a blender and stored in bottles for later vitamin and protein analyses.

While the system was in operation, solids, pH, and sludge content determinations were run daily. BOD determinations on the raw waste and effluent were made three times each week. Sludge content was determined by centrifuge and reported as per cent by volume. No control of sludge volume was attempted. The assumption was made that as long as the sludge was in good condition and settled well, and if the degree of good treatment was satisfactory, then the system was in good condition. The sludge content varied from 11 to 32 per cent.

The thiamin content of the dry sludge samples was determined by the thiochrome method (5), niacin by a colorimetric method (6), and riboflavin, pantothenic acid, and vitamin B_{12}, microbiologically (7)(8)(9). The culture mediums used in the microbiological analyses were obtained in the dehydrated form from a commercial laboratory.* The crude protein content was arrived at by multiplying the per cent Kjeldahl nitrogen by a factor of 6.25.

Results

This study was composed of 15 separate runs from which were collected 15 individual sludge samples. Table I gives the average per cent organic solids and BOD of the raw waste and

* Difco Laboratories, Detroit, Mich.

the effluent plus the per cent reduction in each of the 15 runs. It should be pointed out that a portion of the solids in citrus waste waters are small particles of pulp which, in turn, are mostly cellulose. These particles, being relatively stable and not easily broken down by biological action, influence the solids values but not the BOD values. The BOD values are therefore the best criterion for determining the degree of treatment obtained. Table I shows that a BOD reduction of over 99 per cent was obtained in each of the 15 runs regardless of the amounts of inorganic nutrients being used. This indicates somewhat more conclusively the hypothesis that nitrogen and phosphate nutrients are not needed for good treatment when working with a healthy, well-established activated sludge culture. However, it has been shown that

TABLE II.—Effect of Nitrogen and Phosphate Nutrients, Cobalt, and Method of Drying on the Thiamin, Vitamin B_{12}, Niacin, Riboflavin, and Protein Content of Dry Excess Activated Citrus Sludge

Sample No.	$NaNO_3$ used (ppm N)	Na_3PO_4 used (ppm PO_4)	$CoCl_2$ used (ppm Co)	Drying Method	Thiamin (mcg/g)	Vitamin B_{12} (mcg/g)	Niacin (mcg/g)	Riboflavin (mcg/g)	Protein (%)
(*a*) The Effect of Drying Method									
4	0	0	0	Oven	0.15	1.99	9.15	26.00	33.11
14	0	0	0	Drum	3.3	12.62	8.10	23.20	34.27
(*b*) The Effect of Nitrogen									
8	0	10	2	Drum	7.4	17.50	10.90	21.28	29.19
9	10	10	2	Drum	4.3	19.63	12.10	26.28	33.81
4	0	0	0	Oven	0.15	1.99	9.15	26.00	33.11
3	10	0	0	Oven	0.00	2.63	9.15	32.00	37.61
(*c*) The Effect of Phosphate									
15	0	0	2	Drum	9.6	13.94	7.75	24.00	31.24
8	0	10	2	Drum	7.4	17.50	10.90	21.28	29.19
(*d*) The Effect of Cobalt									
4	0	0	0	Oven	0.15	1.99	9.15	26.00	33.11
5	0	0	1	Oven	0.46	9.13	7.65	20.00	28.90
3	10	0	0	Oven	0.00	2.63	9.15	32.00	37.61
7	10	0	2	Oven	2.7	13.40	9.00	21.60	33.11
10	10	10	1	Drum	4.6	17.88	9.09	25.20	31.01
9	10	10	2	Drum	4.3	19.63	12.10	26.28	33.81
14	0	0	0	Drum	3.3	12.62	8.10	23.20	34.27
15	0	0	2	Drum	9.6	13.94	7.75	24.00	31.24
(*e*) The Effect of Nitrogen + Phosphate									
4	0	0	0	Oven	0.15	1.99	9.15	26.00	33.11
2	25	10	0	Oven	0.59	2.06	9.89	31.20	36.13
1	50	21.6	0	Oven	0.28	2.21	10.68	37.60	42.55
14	0	0	0	Drum	3.3	12.62	8.10	23.20	34.27
13	25	12.5	0	Drum	2.3	23.13	9.52	32.80	41.73
12	50	25	0	Drum	1.1	19.00	10.66	24.00	40.33
11	100	50	0	Drum	0.38	24.88	11.42	36.80	43.83

the use of these materials is essential in establishing a new culture.

Table II gives the results of the B group vitamin and protein analyses on 14 samples of the dried activated sludge. It also gives comparisons that demonstrate the effect of the different variables on the vitamin and protein content of the dry material. The sample numbers in Table II correspond with the run numbers in Table I. It is shown in Table II that the method of drying influenced greatly the amounts of thiamin and vitamin B_{12} found in the dry product. Drying in an oven at 105°C for 24 hr was apparently too harsh and destroyed a large portion of both materials. Since drying the sludge on a drum dryer exposed the material to a higher temperature than the oven method, it appears that the length of time the material is exposed to an elevated temperature is critical. It has been reported (10) that, under the conditions at which these materials were dried, thiamin will decompose and vitamin B_{12} will lose activity. The method of drying did not appear to effect the amount of the other vitamins and protein in the dry sludge.

The addition of nitrogen had a depressing effect on the thiamin content of the sludge. For example, treatment conditions resulting in sample number nine, containing 4.3 mcg of thiamin/g, differed from those resulting in sample number eight, containing 7.4 mcg/g, only by the addition of 10 ppm nitrogen. However, the addition of nitrogen was beneficial in the production of the other B vitamins and, as was expected, was a direct influence on the protein content. The highest protein content was obtained when using the highest nitrogen level.

Phosphate addition decreased the production of thiamin, riboflavin, and protein but increased the vitamin B_{12} and niacin production.

The addition of cobalt to the system brought about a very large increase in the vitamin B_{12} content even when the material was treated harshly by drying it in the oven. The effect of the cobalt was much more pronounced, however, when added with small amounts of nitrogen or phosphate. Cobalt also increased the thiamin production. Effect on the other vitamins and protein was negligible.

The effect of the addition of nitrogen and phosphate together was to add the effects of each individual nutrient. In the results given in the last section of Table II the amount of nitrogen used was, in all cases, at least double that of the phosphate. In the production of riboflavin and protein where nitrogen was beneficial and phosphate detrimental, the excess of nitrogen used offset the effect of the phosphate. In the cases of vitamin B_{12} and niacin, where both nutrients were beneficial to the production, and the case of thiamin, where both were detrimental to the production, the effects of the nutrients were additive.

The pantothenic acid results were not included in Table II because they showed no definite pattern to indicate that the nutrients used or the method of drying had any effect on the amount of that ingredient found in the dried sludge. The mean value for pantothenic acid was 20.67 mcg/g and the standard deviation was 10.76 mcg/g.

Discussion

The work done to date indicates that the excess sludge obtained from the treatment of citrus waste waters by the activated sludge process does contain appreciable amounts of B group vitamins and large quantities of protein.

The value of this excess sludge as an animal feed supplement would probably be in the protein content. The protein content is similar to that of cotton seed meal, now used as a protein supplement in animal feeds.

If the excess sludge could be used as a chicken feed supplement the value

would probably lie more in the vitamin B_{12} content. The proportions of the different amino acids are more important in poultry feeds than is the total amount of protein.

Although the results of the vitamin and protein analyses indicate that dry, excess, activated citrus sludge might be used as a source of these substances in animal or chicken feed supplements, a few unanswered questions stand between the theoretical and the actual use of the material for this purpose. These questions involve such subjects as (a) toxicity, (b) storage life, (c) amino acid content, (d) production and demand, (e) production costs, (f) monetary value of the product and (g) the production of a material having a constant vitamin and protein content. The answers to some of these questions lie in the use of a much larger activated sludge system than was available in these studies.

Conclusions

1. The dry, excess sludge from the treatment of citrus waste waters by the activated sludge process contains significant quantities of the B group vitamins (thiamin, niacin, riboflavin, pantothenic acid, and vitamin B_{12}) plus a high protein value.

2. The quantities of those vitamins and protein found were much larger than were found in the earlier work.

3. The vitamin B_{12} content places it in a position to be considered as a vitamin B_{12} supplement in chicken feeds.

4. The vitamin content is directly affected by any inorganic nitrogen or phosphate added to the system as nutrients.

5. The addition of small quantities of cobalt to the system increases the vitamin B_{12} and thiamin content of the final dry sludge.

6. Exposure of the material during drying to 105° C for 24 hr will destroy a large portion of the vitamin B_{12} and thiamin. Drum drying is superior to oven drying.

7. The protein content of the dry excess sludge ranged from 28.90 per cent to 43.83 per cent, which is high enough for it to be considered as a protein supplement in animal feeds.

8. The protein content is increased by increasing the amount of nutrient nitrogen used.

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BASIC DATA FOR CHEMICAL WASTE DISPOSAL *

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As the industrial community of our nation continues to grow in size and complexity, increasing and more careful planning and consideration must be given to requirements for the satisfactory disposal of its waste products. Of particular concern are chemical wastes; those from the segment of industry engaged in manufacturing processes of a chemical nature. Such wastes are extremely complex and there are wide variations in their chemical and physical properties in comparison to the relative uniformity of domestic wastes. For this reason, and also because they may encompass both organic and inorganic compounds, generalizations with respect to disposal are usually not possible; in most cases methods for satisfactory disposal must be tailored to fit each waste. These waste disposal problems require, and are being given, the same thought and detailed study as the problems of production. The picture continues to improve as industry learns more about processing waste materials so that their release gives no offense to others. New tools and techniques are constantly being developed and put into use.

Recognition of Problems

It is the purpose of this paper to discuss briefly some of the benefits to be derived from early recognition and study of waste disposal problems and to describe some of the difficulties experienced in obtaining basic data for evaluating disposal requirements. These comments are based on experience with water-borne or liquid wastes but the principles apply equally well to wastes that are air-borne.

Industry recognizes that it is important to have those who will be responsible for the development of a new process or product become fully conversant with the role waste disposal must play in the over-all picture. Early consideration of alternate methods of manufacture with waste disposal requirements in mind will often save dollars and eliminate headaches later on. One important aspect is the selection, where possible, of raw materials whose use will minimize the problem of ultimate disposal. Some examples of beneficial product substitution may make this point clearer.

Product Substitution

For decades, starch has been used by the textile industry as a carrier for dyes on printed cloth, as a finish for woven goods, and for many other purposes. Wastes from these operations have been high in BOD and have contributed to the overloading of many streams. Recently developed plastic finishes may be substituted, in many instances, for the starches. Their use has reduced the BOD of wastes in established plants and may tip a pollution balance to make possible the starting of a new plant at a site that could not otherwise be considered due to limitations on plant discharges.

A second example relates to an operation which had used an organic acid in one phase of manufacture for many years. When BOD became a problem, investigation proved that a mineral acid could be substituted without damage to the product quality or yield and

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resulted in a substantial lowering of the BOD of the waste.

A third instance concerns a manufacturing process which could proceed along either of two routes. If one was followed, the plant effluent would contain soluble salts in quantities that would make the quality of the receiving stream unsatisfactory to downstream users during periods of low stream flow. An alternate process was selected because its wastes contained insoluble salts that were readily filtered out, thus relieving the stream of an additional burden of dissolved solids.

Process Modification

At times modifications to the actual process, beyond those dictated by process economics, may be incorporated with the result that a much lower production-plus-waste-treatment cost will be realized than would be the case if the two problems were considered independently. As an example, it is possible to examine a process in which the recovery of a volatile solvent with a high BOD was necessary. Process economics, disregarding treatment to reduce this oxygen demand, dictated that the water-bearing solvent mixture should be distilled until a definite amount of solvent had been removed, leaving a small residue for discharge; small, that is, until its oxygen demand was recognized. Two avenues were open: treatment of the wastes to reduce its BOD, or reduction of the remaining solvent fraction. Fortunately, those responsible for designing the process recognized the total problem and elected to increase the amount of solvent removed by increasing the size of distillation columns in which it was recovered. Although the equipment and operating costs resulting from this change were somewhat higher, the oxygen demand of the waste was reduced to a point where treatment was not necessary. As a result, the total cost was well below that which would have resulted had each problem been considered separately.

Waste Characteristics

Basic data on waste characteristics may be divided into two broad categories: those of a chemical and those of a physical nature. Even a partial list of chemical properties must include oxygen demand (chemical and biochemical), toxicity, acidity and/or alkalinity, pH, and inorganic salts content. The physical aspects to be considered include taste, odor, color, temperature, undissolved solids content, and volume.

Testing Techniques

In many cases BOD and toxicity are two characteristics of chemical wastes that have required the most careful study. It has been found that grossly misleading results are often obtained if the BOD determination is carried out by those unfamiliar with the biological aspects of the test. Two examples will illustrate this point.

BOD results obtained in a control laboratory on a waste were astonishingly high when compared with results, which were felt to be correct, on a similar waste from another plant. The work in both laboratories was done by competent chemists accustomed to procedures and techniques common in industrial laboratories. A careful review of the procedure used revealed no apparent reason for the high values obtained in the control laboratory until a casual remark disclosed that an alcoholic indicator solution had been added to each sample to facilitate adjustment of the pH to approximate neutrality as required by "Standard Methods." The chemist in charge explained that, in procedures with which he was familiar, it was customary to so specify when the use of an external indicator was required. Lacking such a warning he innocently used an internal one and was therefore determining the BOD, not only of the waste,

but of the alcoholic portion of the indicator. With the elimination of this error, results duplicated, to a satisfying degree, those obtained elsewhere on a similar waste stream.

In another case BOD results were puzzlingly low until a careful check on the procedure being used disclosed that the analyst was not shaking the sample bottles between the addition of the alkaline potassium iodide solution and acid. With this step included, results were more reasonable.

Analysts should never forget the purpose of the BOD test which is to reproduce, as closely as is practicable, conditions which may be expected to occur following waste discharge into receiving waters. Misleading analytical results frequently are obtained when seed material is not properly acclimated. Those accustomed to analyses based on chemical reactions do not always appreciate the fact that the BOD test depends on the action of living organisms which are not normally found in chemical wastes and which must be added if the biochemical demand is to be measured. The addition of sewage as a source of seed organisms is frequently not enough; to be useful the organisms must have been growing in an environment in which the wastes being tested have been present so that they have become accustomed to such wastes. If this is not done, all too frequently they are either killed when added to a sample containing relatively high concentrations of wastes or their activity is materially diminished. As a result, low values will be obtained. In some instances waste concentrations are high enough to kill completely all life in the sample bottles and, from the lack of reduction in the dissolved oxygen content at the end of five days, the impression is given that the waste had no biochemical oxygen demand. This source of error can be eliminated by the use of acclimated seed and a sufficient number of dilutions so that any repressive effect will be seen when comparing calculated BOD's in the series of dilutions; if the higher dilutions have higher values, biological activity is being slowed down and results are subject to question.

Laboratory Facilities

The provision of laboratory facilities for making BOD tests cannot always be justified, particularly if the number of samples is small or requirements for such tests are infrequent. Under such conditions assistance is readily available from many universities, from commercial laboratories, and from some scientific groups. Frequently state agencies also have laboratory facilities of this type and will assist in obtaining these data.

Toxic Properties of Wastes

Practical evaluation of the toxic properties of wastes may be said to have begun in the mid 40's with the work of Hart, Doudoroff, and Greenbank (1). Since that time bio-assay methods have continued to be developed and now include measurement of toxic effects on other members of the life cycle in receiving waters. While the value of data on the biologically safe concentration of a waste with respect to fish is important if fish kills are to be avoided, it is of equal importance to have similar information on other parts of the aquatic life cycle, such as insects and algae which serve as fish food. If these are destroyed, fish will seek food elsewhere, leaving the area just as devoid of piscatorial life as though they had all been poisoned.

Receiving Waters

In addition to a study on problems of waste characteristics, recognition must be given to the need for careful consideration of the characteristics of receiving waters. Among those properties which should be evaluated are the size or volume, the type (flowing, impounded, or tidal), and the present and future uses to which it may be put.

Most wastes are ultimately discharged to some body of water and the volume available for dilution is of immediate and primary importance. It is a simple matter to calculate concentrations which may be expected when given wastes are completely mixed with known volumes of water. Care should be taken at this point, however, to consider how much of the total capacity for dilution is available from a practical standpoint. It would be dangerous to assume that safe conditions, resulting from adequate dilution, will be achieved unless specific means are provided for prompt mixing of wastes and water. Factors to be considered include: the shape of the receiving body of water, quantity, velocity, turbulence of flow, salinity, and thermal stratification.

With dilution requirements known, thought must be given to the relative specific gravity of plant effluents and waters into which they discharge. For example, the initial study of characteristics of a small, tidal river, coupled with complete data on properties of the combined wastes-cooling water effluent under consideration, led to the conclusion that their discharge would create no problem. River tests, however, disclosed a bottom layer of salt water which decreased in density as the surface was approached. The top 4 ft were essentially salt free. The density of the plant effluent was between that of the upper and lower layers and, when anticipated results in the stream were not achieved, it was found that the effluent was traveling as a density current in a 2- to 3-ft layer some 7 to 10 ft below the surface. A possible remedial measure would be to use the fresh, less dense surface water for cooling. This change would decrease the density of the effluent and cause it to rise and mix more promptly with the upper layers of oxygen-rich water, thus satisfying the oxygen demand more quickly.

Estimating the degree of mixing to be obtained in waters of a tidal nature frequently presents a difficult problem. The use of hydraulic models of river basins, such as those at the U. S. Army Corps of Engineers Waterways Experiment Station at Vicksburg, Miss., has made it possible to find answers to some dispersion problems which could not otherwise be solved except by means of expensive, full-scale tests.

Conclusions

Industry has come a long way in recent years in finding answers to problems of waste treatment and disposal of ever-increasing complexity. The need for clearer definition of the characteristics of both wastes and receiving waters is being recognized. New techniques for providing such data are being discovered and there is broader and more comprehensive understanding of old ones. It is axiomatic that increasing restrictions and stream quality requirements necessitate continuing advances in this area if industry is to continue to grow and expand.

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COLOR REMOVAL IN WASTE-WATER TREATMENT PLANTS

By N. L. Nemerow * and T. A. Doby

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At various times sights must be readjusted on the over-all objectives of waste-water treatment. The day has passed when a waste having undergone 90 per cent BOD reduction and 95 per cent suspended solids reduction may be discharged safely into a receiving stream. Today consideration must be given, among other things, to toxic metals, phenolic compounds, bacterial reduction, and the appearance of the river after it has received the effluent. The appearance of a stream does not necessarily indicate the quality or quantity of material contained therein. However, first impressions are important and usually highly indicative of over-all conditions. If no effort has been made to remove the obvious pollution, the public assumes that little effort has been expended in removing the other forms of polluting matter. Unnatural color in a stream symbolizes to the average observer that a river is polluted. It is sometimes easier to remove the color from the river than to erase the often erroneous conception from the minds of the observers.

For these reasons, consideration should be given to means of removing color from waste-waters. Some studies in this area have already been undertaken (1)(2). It should be of primary concern to know how much color is being removed in present day operating municipal treatment plants. Current color removal efficiencies in these plants have been the objective of this study.

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Procedure

The method of study has been divided into two phases:

1. A questionnaire was sent to 386 superintendents of treatment plants throughout the United States. The 138 replies were analyzed carefully and the results are presented in Tables I, II, III, IV, V, and VI.

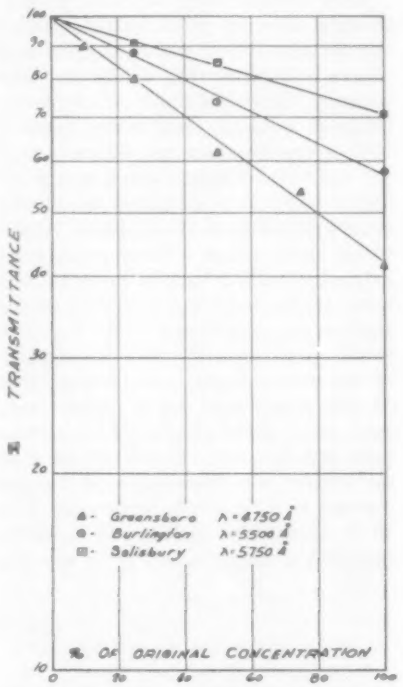

FIGURE 1.—Verification of Lambert-Beers Law for waste-water influent samples for three municipal waste-water treatment plants in North Carolina.

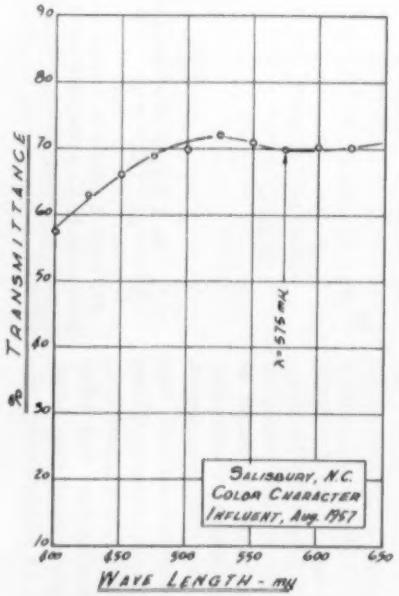

FIGURE 2.—Curve showing determination of wave length of minimum transmittance for waste-water influent to Salisbury, N. C., treatment plant.

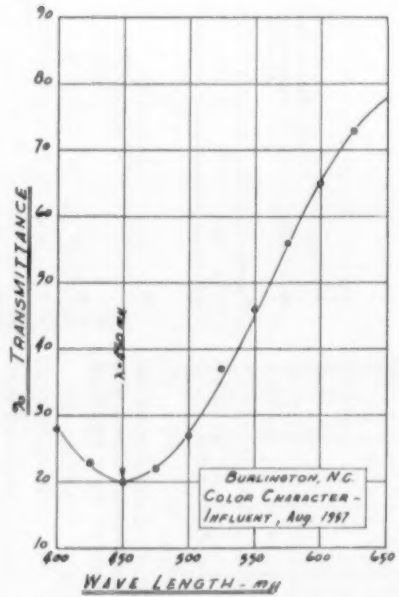

FIGURE 3.—Curve showing determination of wave length of minimum transmittance for waste-water influent to Burlington, N. C., treatment plant.

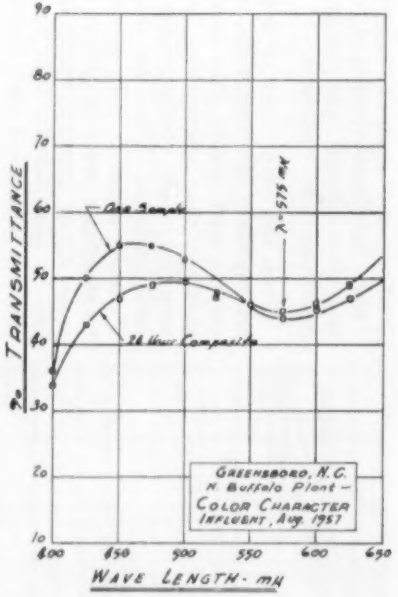

FIGURE 4.—Curve showing determination of wave length of minimum transmittance for waste-water influent to Greensboro, N. C., treatment plant.

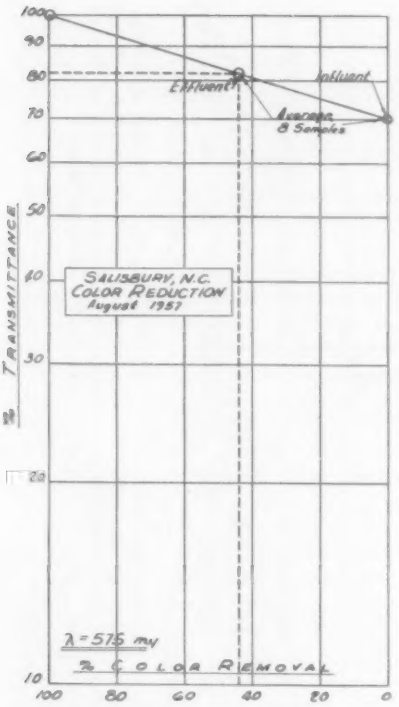

FIGURE 5.—Color reduction curve for Salisbury, N. C., waste-water influent with a minimum transmittance wave length of 575 mμ.

2. Three field experiments were carried out at the Burlington, Salisbury, and Greensboro, North Carolina, municipal sewage treatment plants. Influent color curves were determined by measuring the light transmitted at various wave lengths in the visible range of the spectrum. The Lambert-Beers Law relating to color concentration and transmittance was found to be valid for each colored waste-water sample (Figure 1). The wave length of minimum transmittance (λ) was ascertained from the curves. These curves are illustrated in Figures 2, 3, and 4. The detention time and influent color characteristics at each plant were determined by mathematical calculations and analysis, respectively. Color (light transmittance at all visible wave lengths) was measured by Spectronic "20" machines.

From the wave length of minimum transmittance determinations, curves for the same plants were developed, showing the relationship between measured light transmittance and color reduction. These are shown in Figures 5, 6, and 7. After a minimum transmittance wave length is determined for an influent, effluent samples can be measured for light transmittance at the selected wave length, and from a curve (Figures 5, 6, and 7) the per cent color reduction can be obtained.

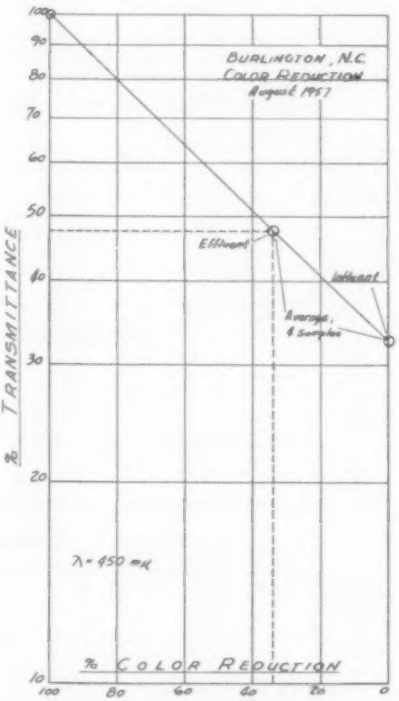

FIGURE 6.—Color reduction curve for Burlington, N. C., waste-water influent with a minimum transmittance wave length of 450 mμ.

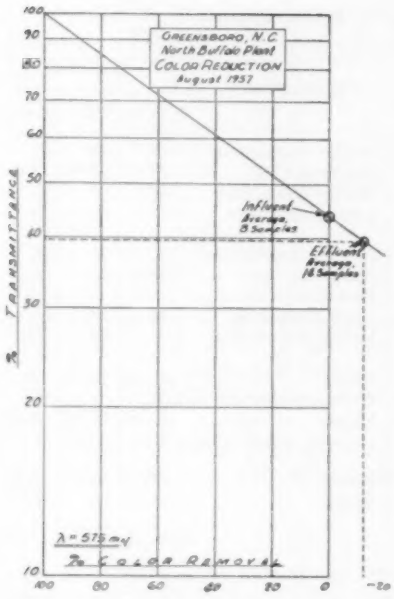

FIGURE 7.—Color reduction curve for Greenboro, N. C., waste-water influent with a minimum transmittance wave length of 575 mμ.

Discussion

Survey Analysis

Despite the simplicity of the questionnaires only about 36 per cent of them were returned (Table I). Of these, only 50.7 per cent disclosed that color is present in the sewage. Only 20 per cent of those having a color problem measure it. This meant that it was necessary to work with data from only 14 plants in order to compute color removal efficiencies.

TABLE I.—Extent of Color Problem

No. of Questionnaires*	No. of Replies	Plants with Color Present		Plants Which Measure Color	
		No.	% of Replies	No.	% of Replies
386	138	70	50.7	14	10.1

* List taken from 1952 membership of Federation of Sewage and Industrial Wastes.

TABLE II.—Analysis of Plants Measuring Color

No. Plants, Total	Type Treatment			Measuring Device Used	
	Primary	Trickling Filter	Activated Sludge	Transmitted Light	Reflected Light
14	3	4	7	7	7

It is apparent that a very small proportion (only 10 per cent in this survey) of municipal plants are concerned about the color problem sufficiently to measure color. This is probably due to a combination of the lack of an inexpensive, significant, and standard method of measuring color and an understanding of its effect upon the receiving stream.

Seven plants measuring color were of the activated sludge type; four, trickling filter; and three, primary (Table II). Half the plants measuring color concentration utilize instruments operating on transmitted light and the other half use reflected light devices.

The description of the 14 plants measuring color and their efficiencies (Table III) shows that they are located predominantly in heavily industrialized and highly populated northern and midwestern cities. Color originates from a variety of industrial wastes. Most plants measuring color are removing some of the color.

The activated sludge plants (Table IV) report the removal of 93 per cent of the color when more than 90 per cent BOD and suspended solids are also removed. However, it should be kept in mind that the plants reporting are those which are most concerned about color removal. These plants, therefore, presumably concentrate more upon removing color than other activated sludge plants.

TABLE III.—Color Removal by Municipal Plants

Location	Type Plant*	Color Source	Measuring Device	% Removal		
				BOD	ss	Color
Gastonia, N. C.	1	Textile dyes	Hellige comparator	81	78	67
Salisbury, N. C.	2	Textile dyes	Spectronic "20"	74	73	15.4
Orlando, Fla.	2	Sewage only	Hellige comparator	84	87	90
Little Ferry, N. J.	1	Textile dyes	Lertz photometer	71	89	10
Springdale, Ark.	2	Grape juice and potatoes	Jackson turbidimeter	50–90	95	70
York, Pa.	1	Dyes	Spectronic "20"	95.3	95	86
Altoona, Pa.	1	Blood, plating	Beckman B spectrophotom.	80	70	95
Manville, N. J.†	5	Paper	Hellige comparator	95	55.1	59.2
Findlay, Ohio	1	Canning, chemical	Visual	85–90	85–90	100
Norristown, Pa.	1	Brewery	Hellige comparator	95	94.3	88
Charlotte, Mich.	3	Milk, dyes, alum	Visual	80–85	65–75	90–95
Springfield, Mass.	4	Ind. wastes	Jackson turbidimeter	26	50	31
New Britain, Conn.	4	Steel pickling, metal plating	Visual	60–70	60–80	50–60
Covington, Ohio	1	Milk	Visual	98	96	100

* Legend for type plants.
1—Activated sludge
2—High-rate trickling filter
3—Standard-rate trickling filter
4—Primary treatment
5—Lagoon
† Industrial waste only.

The trickling filter plants (Table V) report the removal of 84 per cent of the color when 75 to 90 per cent of the BOD and suspended solids are removed. The Salisbury, N. C., plant efficiencies were not included in the averages since it obtained somewhat lower BOD and suspended solids removal. However, this may be more typical of a trickling filter plant handling certain types of color than the other three plants. Although the filter plants report less color removal than the activated sludge plants, only three filter plants were used in computing the average. There is some danger in forming rigid conclusions on such a small number of plants.

TABLE IV.—Color Removal by Activated Sludge Plants

Plant	Per Cent Removal		
	BOD	ss	Color
York, Pa.	95.5	95	86
Findlay, Ohio	90	90	100
Norristown, Pa.	95	94.3	88
Covington, Ohio	98	96	100
Altoona, Pa.*	90	90	100
Little Ferry, N. J.*	71	89	10
Gastonia, N. C.*	81	78	67
Averages	94.4	93.8	93

* Overloaded plants excluded from averages.

TABLE V.—Color Removal by Trickling Filter Plants

Plant	Per Cent Removal		
	BOD	ss	Color
Salisbury, N. C.*	74	73	15.4
Orlando, Fla.	84	87	90
Springdale, Ark.	50–90	95	70
Charlotte, Mich.	80–85	65–75	90–95
Averages	78	87	84

* Omitted from averages.

TABLE VI.—Color Removal by Primary Plants

Plant	Per Cent Removal		
	BOD	ss	Color
Springfield, Mass.	26	50	31
New Britain, Conn.	60–70	60–80	50–60
Averages	45	60	43

The two primary plants (Table VI) report the removal of only 43 per cent of the color when 45 to 60 per cent of the suspended solids and BOD are removed. As could be expected, the color removal is poorest in primary plants, intermediate in trickling filter plants, and highest in activated sludge plants.

Field Experiments

In these field experiments, no pH adjustments were made. It was felt that any pH adjustment in the actual treatment process resulting in a color change should be included in treatment efficiency. This efficiency should be recorded as color increase or decrease in the plant at the given pH value. If the pH is changed artificially during color measurement, it is believed that this will not be a valid indication of the color removal efficiency of the plant.

No turbidity measurements were made. Turbidity affects the amount of light transmitted non-selectively. If it is assumed that the influents contained more turbidity than the effluents, the relative color removals reported would be greater than those actually occurring in non-turbid samples.

Therefore, in the use of the curves developed for color reduction it must be remembered that various industrial wastes can be responsible for variable pH and turbidity conditions, thereby requiring careful evaluation of color reduction curves (Figures 5, 6, and 7). These curves further indicate the variable basic conditions found in different treatment plants as the result of different industrial wastes.

Conclusions

1. Although 50 per cent of the replies received to a questionnaire indicated interest in color removal at their municipal plants, only 10 per cent of the plants responding measure color.

2. Those plants measuring color and apparently operating satisfactorily on a normal pollutional load report the following efficiencies of color removal:

Treatment Type	Color Reduction (%)
Primary plants	43
Trickling filter plants	84
Activated sludge plants	93

3. Field experiments carried out on three North Carolina municipal plants which are highly loaded with industrial wastes showed the following color removal efficiencies:

Plant	Color Removal (%)
Primary plant (Greensboro)	−12
Standard-rate trickling filter plant (Burlington)	+34
High-rate trickling filter plant (Salisbury)	+44

4. In the future it is estimated that more attention will be given to the color problem in waste-water and its reduction in municipal treatment plants handling industrial wastes.

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Stream Pollution

A GRAPHICAL SOLUTION OF THE OXYGEN-SAG EQUATION

By T. A. Wastler and N. D. Wastler

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Many stream self-purification calculations and estimates depend upon the Streeter-Phelps oxygen-sag curve. The equation originally derived (1) for this curve is

$$D_t = \frac{k_1 L_a}{k_2 - k_1}(10^{-k_1 t} - 10^{-k_2 t}) + D_a(10^{-k_2 t}) \quad (1)$$

D_t represents the deficit in ppm between actual dissolved oxygen and saturation at a time t, which is the time of water travel measured along the stream from an initial point. D_a is the saturation deficit of dissolved oxygen in ppm at the initial location, and L_a is the ultimate first-stage BOD at the initial point. The coefficients k_1 and k_2 represent specific rate constants for deoxygenation and reoxygenation in the flowing stream. The numerical values of k_1 and k_2 depend upon the units for measuring time t.

The sag equation cannot be solved explicitly for k_1 or k_2. The variable k_1 can be calculated from laboratory data. The variable k_2 is difficult to measure directly; therefore, when Equation 1 is used to determine k_2, a series of trial-and-error solutions is usually required. In order to reduce these calculations, numerous simplifications, approximations, and specific solutions to fit special conditions have been derived (2) (3) (4) (5). For example, Streeter (2) has presented a series of straight-line nomographs which are useful in evaluating the nonexponential variables in the equation. The general nomograph presented here solves the oxygen-sag equation exactly, eliminating the trial-and-error solutions for k_2.

Development of the Graphical Solution

As suggested by Fair (3), let $f = \frac{k_2}{k_1}$; then

$$k_1 f = k_2 \quad (2)$$

and

$$\frac{1}{f-1} = \frac{k_1}{k_2 - k_1} \quad (3)$$

Substitute Equations 2 and 3 into Equation 1:

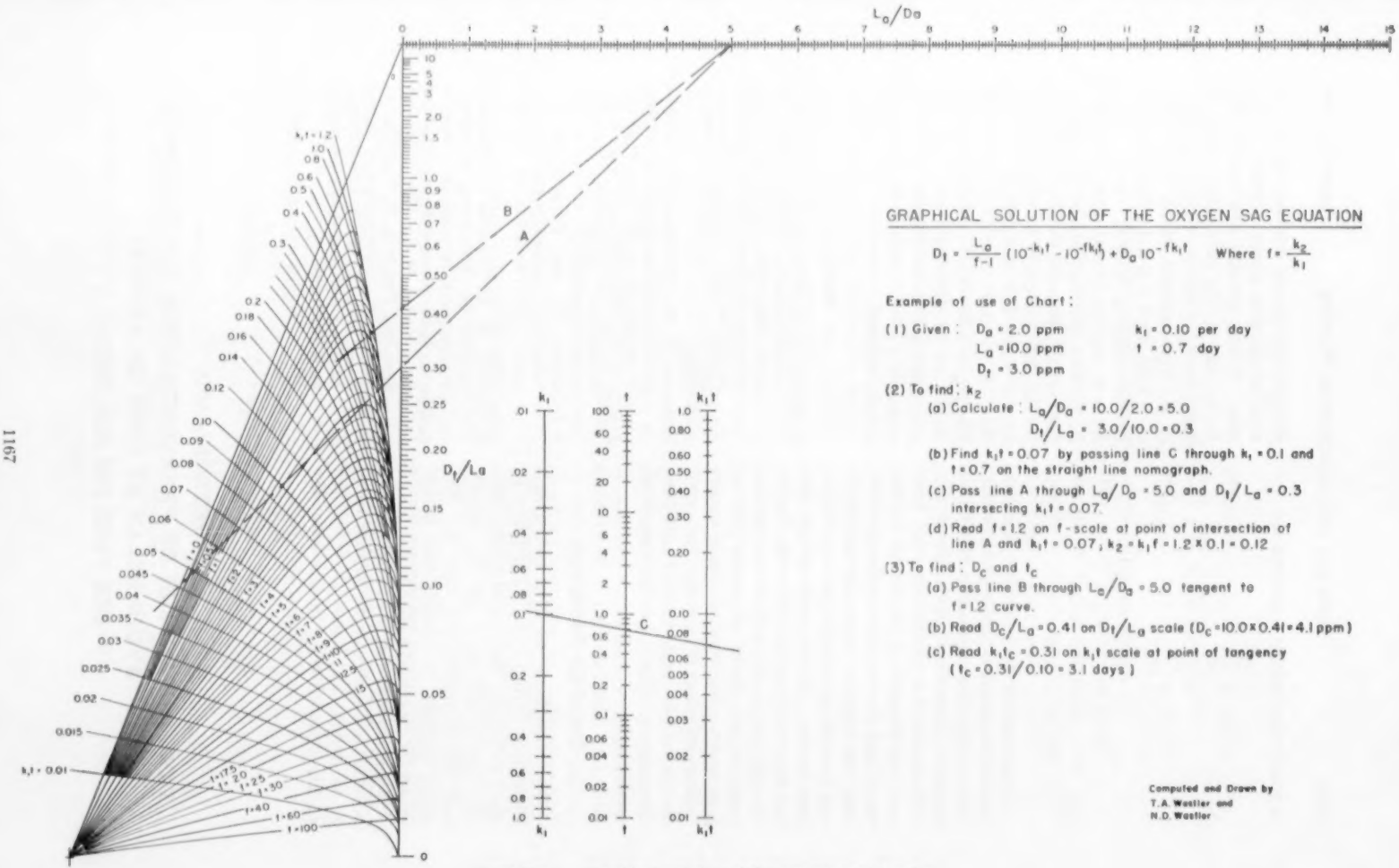
$$D_t = \frac{L_a}{f-1}(10^{-k_1 t} - 10^{-f k_1 t}) + D_a(10^{-f k_1 t}) \quad (4)$$

Rearrange Equation 4 to obtain:

$$10^{-f k_1 t} = \frac{D_t}{D_a} - \frac{L_a}{D_a} \times \frac{(10^{-k_1 t} - 10^{-f k_1 t})}{f-1} \quad (5)$$

Regard f, k_1, and t as a composite variable; Equation 5 then has the form

$$F_4(w) = F_1(u) - F_2(v)\, F_3(w) \quad (6)$$



GRAPHICAL SOLUTION OF THE OXYGEN SAG EQUATION

$$D_t = \frac{L_o}{f-1}\left(10^{-k_1t} - 10^{-fk_1t}\right) + D_o\,10^{-fk_1t} \qquad \text{Where } f = \frac{k_2}{k_1}$$

Example of use of Chart:

(1) Given: $D_o = 2.0$ ppm, $k_1 = 0.10$ per day
$L_o = 10.0$ ppm, $t = 0.7$ day
$D_t = 3.0$ ppm

(2) To find: k_2

(a) Calculate: $L_o/D_o = 10.0/2.0 = 5.0$
$D_t/L_o = 3.0/10.0 = 0.3$

(b) Find $k_1t = 0.07$ by passing line C through $k_1 = 0.1$ and $t = 0.7$ on the straight line nomograph.

(c) Pass line A through $L_o/D_o = 5.0$ and $D_t/L_o = 0.3$ intersecting $k_1t = 0.07$.

(d) Read $f = 1.2$ on f-scale at point of intersection of line A and $k_1t = 0.07$; $k_2 = k_1f = 1.2 \times 0.1 = 0.12$

(3) To find: D_c and t_c

(a) Pass line B through $L_o/D_o = 5.0$ tangent to $f = 1.2$ curve.

(b) Read $D_c/L_o = 0.41$ on D_t/L_o scale ($D_c = 10.0 \times 0.41 = 4.1$ ppm)

(c) Read $k_1t_c = 0.31$ on k_1t scale at point of tangency ($t_c = 0.31/0.10 = 3.1$ days)

Computed and Drawn by
T.A. Wastler and
N.D. Wastler

FIGURE 1.—Graphical solution of the oxygen-sag equation.

in which the various functions are

$$F_1(u) = \frac{D_t}{D_a} \quad \ldots\ldots\ldots\ldots\ldots (7)$$

$$F_2(v) = \frac{L_a}{D_a} \quad \ldots\ldots\ldots\ldots\ldots (8)$$

$$F_3(w) = \frac{10^{-k_1 t} - 10^{-f k_1 t}}{f - 1} \quad \ldots (9)$$

and

$$F_4(w) = 10^{-f k_1 t} \quad \ldots\ldots\ldots\ldots (10)$$

Equation 6 is the prototype equation for a nomograph consisting of two parallel straight-line axes and a curvilinear function dependent upon them (6). If Equation 5 is plotted directly, however, the location of the curves is awkward, and the requisite scales produce axes too long for a nomograph which can be read accurately, yet be convenient in size. In this instance one axis has been realigned to represent D_t/L_a, the other is L_a/D_a, and the curvilinear function is a family of curves relating f, k_1, and t. Burrows' system of hyperbolic coordinates (7) has also been used to restrict the nomograph to suitable dimensions. Figure 1 is the completed nomograph.

Use of the Nomograph

The directions on the nomograph show how to find f and k_2 and how to use f to find D_c, the critical oxygen deficit (the lowest point on the curve), and the corresponding time t_c. The chart includes a straight-line nomograph for computing $k_1 t$ and t_c.

When the water at the initial location is saturated with oxygen so that there is no deficit, i.e., when $D_a = 0$, then L_a/D_a is undefined. In this case, the straightedge cannot intersect the L_a/D_a axis but must be placed parallel to the axis. If this parallel line crosses the D_t/L_a axis at the calculated point, it intersects $k_1 t$ at the corresponding value of f. For example, if $D_t/L_a = 0.20$, $k_1 = 0.10$, and $t = 1.4$, then $f = 2.0$. In determining critical values when $D_a = 0$, the line is both parallel to the L_a/D_a axis and tangent to the proper f-curve; it intersects the D_t/L_a axis at D_c/L_a, and the point of tangency occurs at $k_1 t_c$. For example, if $f = 2.0$, then $k_1 t_c = 0.30$ and $D_c/L_a = 0.25$. The permissible BOD load can then be calculated by dividing D_c/L_a into the maximum allowable oxygen deficit to maintain a specific minimum dissolved oxygen content.

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BIOLOGICAL BALANCE IN STREAMS*

By Donald C. Scott

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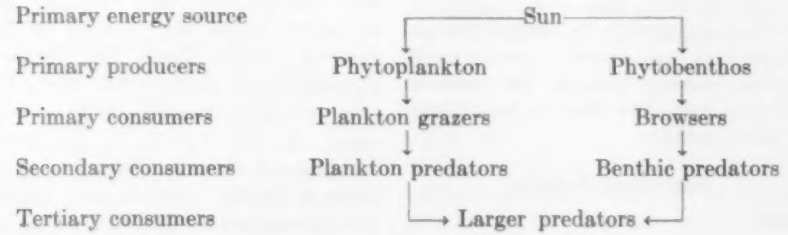
The concept of biological balance in nature was probably first formulated by biologists working on lakes. Lakes are such sharply delimited areas of the environment that they lend themselves readily to consideration as closed biological systems in which nutrient elements are circulated annually. As early as 1887, Stephen Forbes (1) emphasized this fact in his essay entitled "The Lake as a Microcosm." Many lakes are, indeed, practically closed systems whose outflow and inflow are inconsequential when compared with the volume of standing water. Furthermore, in temperate climates, lakes often pass through an orderly and predictable sequence of physical, chemical, and biological changes with the passage of the seasons. These changes tend to assure the annual circulation of energy and nutrients throughout the system.

Food Chain

The organisms inhabiting lakes were classified at an early date according to their habitats. The small floating and drifting forms were called plankton; those forms associated with the bottom, benthos; and the actively free-swimming organisms, nekton. This ecological classification of aquatic organisms is retained today in all phases of aquatic biology. Superimposed upon this classification is another based upon the nutritional position of the various organisms. Thus, there are those organisms which are capable of harnessing the sun's energy with the aid of chlorophyll and producing organic matter from carbon dioxide and water. All such organisms are plants and are referred to as phytoplankton or phytobenthos depending upon where they live. Photosynthesizing plants are designated as the primary producers in a biological system since all other organisms are in one way or another dependent upon them as a source of organic material and thus of energy. The animals, regardless of where they live, are consumers and may be classified as primary consumers (those that feed on the primary producers), secondary consumers (those that feed on the primary consumers), and so on. Such a nutritionally interrelated assemblage of organisms forms a food chain. These relationships may be best illustrated by the following diagram:



* Presented at the First Georgia Industrial Wastes Conference; Atlanta, Ga.; Apr. 11, 1958.

Each level in a food chain is dependent upon the preceding level as a source of energy in the form of organic matter. These materials were originally elaborated by the primary producers and passed on from level to level in variously modified forms. The same concept may be applied to the various chemical elements which are essential to living things (nitrogen and phosphorus, for example). In a closed and balanced system the amount of energy or matter accruing to any given level of the food chain would be, on the average, constant. This energy or matter might be used in several ways. Some of both must be used in the maintenance of the crop of organisms existing at the level in question. Energy so expended would be wasted as heat while the matter would ultimately be returned to the system in crude form in the waste products and dead bodies of the organisms. Some of the energy and matter must be passed on to the next level of the food chain. Bacteria serve important roles in converting excreted substances and dead bodies into substances which may be utilized over again by the primary producers. Unless removed from the system by the harvesting activities of man or some other predator from the outside, all energy must ultimately be wasted as heat and all chemical elements returned to the system in crude form. In a completely closed system there is no inflow, outflow, or loss to sediments, but in lakes in nature these factors may be measured and taken into account when the energy or element flow through the system is studied. This concept of the operation of a body of water was well formulated by Lindemann (2) in 1942. He attempted to estimate the quantities of energy passing through the various functional components of a small lake in Minnesota.

Biological Balance

Lakes

When applied to a typical standing water environment, the term "biological balance" has an unequivocal meaning. A lake may be said to possess a rate of metabolism just as an individual organism. The energy and basic raw materials necessary for life may be rather strictly accounted for and balance sheets drawn up for them. The amounts of energy required for maintenance, growth, and replacement at the various levels may be estimated and annual budgets ascertained for them. Some aquatic communities achieve what is known as a "steady state" in which losses through the outlet and sedimentation are exactly balanced by nutrients and energy entering the system. It is thus easy to see how the concept of biological balance might be applied to such a system.

Streams

On the other hand, the application of these same principles to streams is fraught with many complications and difficulties. Streams differ from lakes in several fundamental characteristics. By definition the water in a stream is constantly flowing in one direction. Thus, there can be no cycling or recirculation of nutrients or chemical elements. Since most stream organisms do not move with the environment except by accident, these organisms are constantly supplied with new medium. The quality and quantity of the water passing any given point depend entirely upon conditions in the watershed upstream. While these conditions vary within limits, and some, such as temperature, may be predicted with fair accuracy, many important environmental factors such as volume and rate of flow and turbidity are dependent upon the vagaries of the weather. Major floods, for instance, certainly have catastrophic effects for many stream organisms, yet these may occur at any month in the year. Streams can thus be characterized as being a highly variable and unpredictable environment as well as one in which there is no opportunity for the recycling of energy or elements.

Plankton

When the various ecological niches in streams are examined, further differences from the lake environment are obvious. These are especially evident when the plankton is considered. Streams can have little in the way of the true planktonic populations which are so important in lakes. A stream must be constantly "seeded" with planktonic organisms from upstream sources such as lakes, ponds, and quiet backwaters which are in communication with the stream. Once in the stream the ability of these plankton organisms to maintain themselves depends largely upon the turbidity and turbulence of the stream. In turbid streams the primary producers may not receive sufficient light to maintain themselves, much less support a population of consumers. Turbulence, while it results in an equal exposure of the primary producers to the energy-giving rays of the sun, produces a certain amount of attrition of these delicate organisms against the suspended solids and the bottom of the stream. While quantitative data are difficult to obtain in most Georgia rivers because of the difficulty of separating plankton from silt, it appears that truly planktonic organisms cannot at present maintain themselves in significant numbers in the streams of this state. The increasing numbers of major impoundments along the principal river systems may materially change this situation by allowing the suspended solids to settle out and by providing constant sources of plankton organisms.

Benthos

The benthos of a stream seems to be more dependent upon the nature of the available substrates and the current speeds than upon other factors. The bottoms of most of the major streams in Georgia are composed of shifting sand. When such bottoms are sampled by ordinary means they are found to be relatively sterile. Repeated dredge hauls transecting these rivers yield little in the way or organisms other than a few fly larvae, worms, and clams. In these same rivers, however, a careful examination of the more or less fixed substrates yields a quite different picture. The trees and brush which fall into the rivers everywhere along the banks, the exposed roots of trees still standing, and the hard clay and rocks exposed in the river beds support surprisingly large and diverse groups of aquatic invertebrates. These organisms which are living either on or in relatively stable substrates in the larger streams appear to be among the most important members of the stream community. The most abundant of these organisms are those which are adapted for straining small particles from the passing water. The net-spinning larvae of caddis flies and midge flies and the water-straining larvae of blackflies are the dominant members of these fixed communities. The nutritional basis of these organisms seems to lie in the suspended particulate organic material which the current of the stream constantly sweeps by them.

When the source of this material is examined it can only be concluded that the relatively sparse plankton of the stream plays a minor role in its origin. In all probability most of the material originates outside the stream itself. When consideration is given to the mass of dead leaves contributed to a stream during the fall season and the organic material washed from the swamps by floods, it is evident that a large part of this material might be derived from the adjacent land.

Primary producers in the form of phytoplankton or phytobenthos have little chance of establishing themselves in quantity in the major rivers. Growths of filamentous algae may be noted on attached surfaces when stream conditions are stable for extended periods, especially in the spring before the leaf growth of marginal trees shades out potentially productive areas. However, the contribution

of these aquatic primary producers to the organic detritus during an annual cycle must be relatively small in the silty southern rivers unless water levels remain extraordinarily stable.

Sampling Technique

In order to sample benthic populations and to test some of these hypotheses a sampling technique has been developed for use in large silty rivers. The basis of this technique is known as a "brush box." It consists of a cube of ¼-in. mesh hardware cloth in which are placed sticks, stones, and other types of stable substrates. These boxes may be placed at comparable depths and current speeds at points where samples are desired. Within a month or so during the summer season these boxes become populated with a variety of organisms which are characteristic of the river at the point in question. The relative abundance of the different species gives some indication of the habitability of the stream for the various groups of organisms. Brush box samples up and downstream from a point of suspected pollution can be compared on a quasi-quantitative basis to determine the effects which the pollution may have had on the fauna of the stream.

It has been possible to make some general observations from brush box sampling. Other things being equal, brush boxes placed in fast water support more organisms than those in slowly moving water. Mild organic pollution produces an increase in the numbers of organisms in boxes in both fast and slow waters. One general conclusion which can be drawn from these observations on large southern rivers is that the important factor supporting the benthic communities is not so much the concentration of suspended organic matter but rather the total amount passing a given point in a certain time. This concept is not new. It was first applied by Butcher (3) to the relationship between dissolved nutrients and algal growths in English rivers.

Summary

The term biological balance cannot be applied to streams in quite the same way it was originally applied to lakes. Annual balance sheets for the energy and elements may be drawn up for any given stretch of stream but it must be recalled that both available energy and elements are much more variable than either of them is in lakes and that a stream is a system which is wide open at both ends; thus, the opportunities for recycling of energy and elements are very limited. In practical terms therefore, biological balance in streams is quite different from the concept as it is applied to lakes. It is not based on a balance of energy or elements, but on the relative abundance of the various organisms composing the communities within the stream.

It has been customary to analyze stream populations in terms of the relative abundance of the various taxonomic and/or physiologic groups represented. The degree of predominance of so-called pollution-tolerant species over pollution-sensitive ones has long been considered a measure of the degree of pollution of a stream. Patrick (4) has attempted to quantify this evaluation and at the same time recognize the seasonal and other variations that occur at so-called "healthy" stations. The point which should be emphasized here is the fact that under normal, unpolluted conditions in many cases (and particularly where photosynthesis is limited by turbidity) the animal population may consist of organisms which are dependent upon outside sources of organic matter. Thus, pollution, if it provides organic matter and no toxicants, need not result in any imbalance of the biota of a stream so long as it is added in quantities which are assimilable, since it simply adds to natural sources. Exces-

sive quantities of organic materials in a readily assimilable form may exhaust the capacity of a stream for reoxygenation and thus limit the populations of organisms to those species capable of withstanding low dissolved oxygen tensions. These populations may, nevertheless, be in "balance" with their environment. These same organisms are present in relatively small numbers in any stream, hence their mere presence is not necessarily an indicator of pollution.

It is believed that the working concept of biological balance in streams has been unduly influenced by earlier work on lakes where a true balance can be said to exist. In streams "balance" in the same sense does not really exist, but should be referred to as "biological diversity." It should also be remembered that the degree of this diversity is dependent upon other factors as well as pollution.

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CORRECTIONS

In the paper, "Significance of Minerals in Waste-Water," by Ralph Stone and John C. Merrell, Jr. (THIS JOURNAL, **30**, 7, 928; July 1958), the first column, headed "USPHS Drinking Water," in Table I, page 929, should contain the following values instead of those listed:

Bacterial:	
Coliform (No./ml)	0.01
Organic:	
BOD (ppm)	—
Ether solubles (ppm)	—
Volatile acids (ppm)	—
Physical:	
pH	—
Turbidity (ppm)[a]	10
Color (ppm)[a]	20
Susp. solids (ppm)	—
Floating solids	—
Odor	Not objectionable
Taste	Not objectionable
Temperature (°F)	—
Chemical:	
Total diss. sol. (ppm)	500[b]
Chlorides (ppm)	250[b]
Fluorides (ppm)	1.5
Toxic metals (ppm)[c]	0.05
Phenols (ppm)	0.001[b]
Boron (ppm)	—
Hardness, $CaCO_3$ (ppm)	—
Nitrates, as NO_3 (ppm)	—
Na (%)	—
Detergents, ABS (ppm)	—

[a] Filtered water.
[b] Recommended.
[c] Arsenic, selenium, hexavalent chromium—0.05 ppm; lead—0.1 ppm.

In the paper, "The Significance of Detention in Sedimentation," by E. B. Fitch (THIS JOURNAL, **29**, 10, 1123; Oct. 1957), the figures in the third column, headed "Overflow Rate (ft./hr.)," under "1-ft. Depth," of Table II, page 1129, should be multiplied by 0.6 to obtain the correct values.

AN EFFECT OF BIOLOGICAL IMBALANCE IN STREAMS

By William A. Cawley

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A startling effect of biological imbalance which, in recent years, has become a problem of considerable magnitude in many areas is the development, below industrial outfalls, of massive growth of filamentous slime encased bacteria. In many cases these infestations have developed in areas where, by the normal standards used to judge waste disposal methods, excellent conditions exist. In these cases the infestations have resulted from a shift in the bacterial predominance to compensate for the introduction of large quantities of food, in a highly dilute form, into the biological environment. Either *Sphaerotilus natans* or *Leptomitus lacteus* have been able, usually, to assume predominance and develop the quantity of organisms required to constitute an infestation. In this country *Sphaerotilus* has been the organism responsible for the major share of this problem. *Leptomitus* appears to be limited to situations of low pH, and little data beyond the statement that they are involved are available on *Beggiatoa*, *Thiotrix*, and *Fusarium*.

This discussion describes attempts to solve a *Sphaerotilus natans* infestation downstream from the Jesup (Ga.) Division of Rayonier Inc.

Waste Data at Jesup

This plant is designed to manufacture from southern pine 600 tons per day of cellulose for use as a raw material in the rayon industry. The process used is one closely akin to the bleached Kraft paper process. A tabulation of a typical analysis of the waste as it enters the river is shown in Table I. BOD and pH are determined in accordance with "Standard Methods" (1) while the COD is the acid permanganate oxygen consumed test shown in the 9th edition of "Standard Methods" (2). The remaining determinations are those developed by the National Council for Stream Improvement (3). The quantity of waste was roughly doubled when the production capacity was increased from 300 to 600 tons per day with the completion of a second mill unit in October 1957.

Stream Data

The receiving body of water for this waste is the Altamaha River which is a stream of considerable size, draining above the mill some 13,600 sq miles, or about a quarter of the state of Georgia. The records of the Doctortown gage (4) just downstream from the mill outfall show a 23-yr average flow of 12,930 cfs, and annual variations from a maximum of 39,000 cfs to a minimum of 1,870 cfs. Although a new minimum which was not shown in the records has been established since the mill operation began, experi-

TABLE I.—Waste Analysis of Pulp Mill Waste at Jesup, Ga.

Item	Amount
BOD (mg/l)	175
COD (mg/l)	300
pH	7.5–8.5
Resin acid (mg/l)	6–8
Mercaptans (mg/l)	6
Sulfides (mg/l)	1.0
Conductivity (μmhos)	1,600
Quantity (mgd per mill unit)*	20–22

* Jesup division consists of two units, each capable of independent operation.

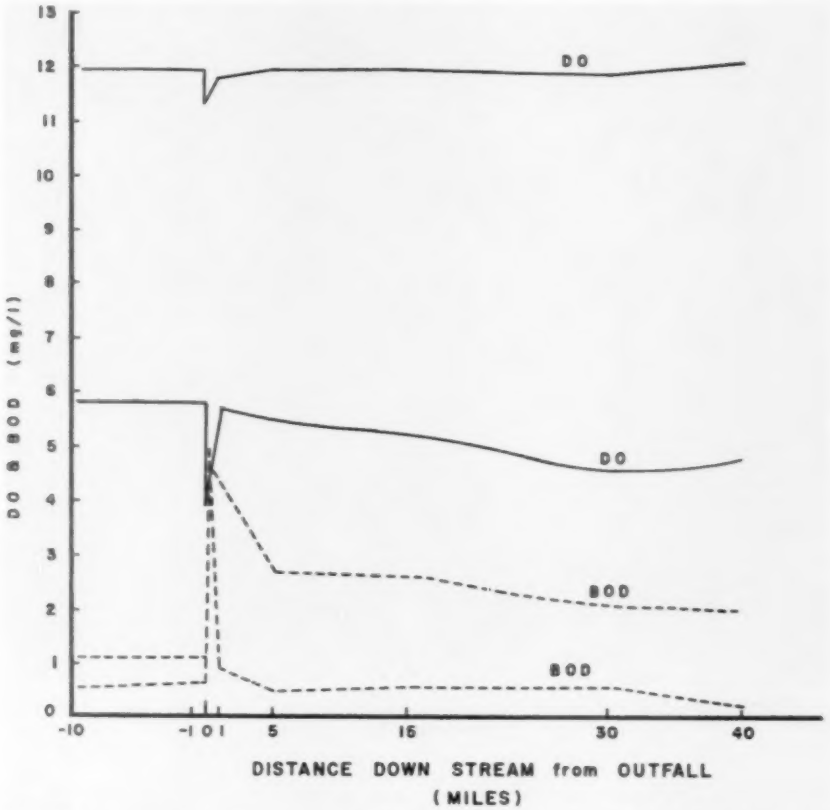

FIGURE 1.—Maximum and minimum dissolved oxygen and biochemical oxygen demand of river for distance of 40 miles below pulp mill outfall.

ence with the 4 to 5 years of operation of the original mill unit showed that, except on rare occasions, a dilution of at least 100:1 was available for the effluent of that mill.

DO and BOD

The data obtained during weekly river trips over the period of mill operation are summarized in Figure 1 in the form of a maximum and minimum DO and BOD curves.

The rather strange shape of these curves in the range 0 to 5 miles is a function of the placing of the sampling points. The zero-mile or outfall samples are collected out of the boil over the end of the sewer. The 200-yd samples (not shown) and the 1-mile samples are collected in the river channel prior to the point where mixing is complete. These samples show that even under these conditions of incomplete dispersion of the waste, sufficient oxygen is available for aquatic life.

Depletions in DO range from the 0.2 to 1.2 mg/l shown with an average depletion of between 0.8 and 1.0 mg/l. The abnormal cold of the winter of 1957–8, which depressed the river water temperature to 4°C coupled with a flow of 30,000 cfs, produced the maximum curve shown. The concentrations represent 90-plus per cent

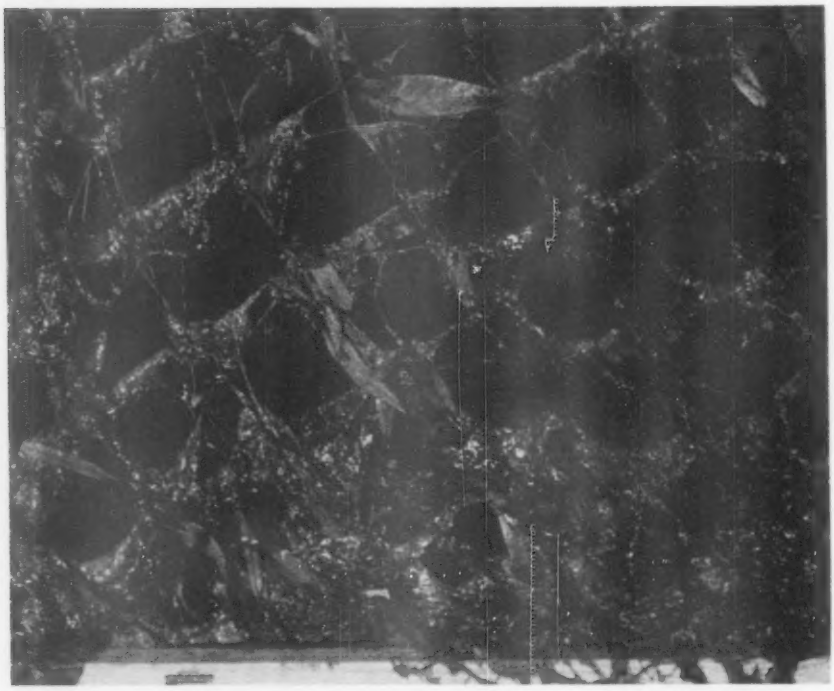

FIGURE 2.—Effect of heavy *Sphaerotilus* infestation on a fishing net after 24 hours of exposure.

saturation. The minimum curve shown here was reached only once in the five years of operation. It represents the combination of low DO water draining out of the swamps on a falling river stage with a unique loading resulting from a mechanical failure in the mill, which had not occurred prior to that time and which has not occurred again. Since the time this situation was recorded, changes in the waste disposal system have been made to eliminate the possibility of a similar recurrence. Depending on river conditions, the curve for any particular day will, of course, lie somewhere between these extremes—usually in the 7 to 8 mg/l range.

The BOD load from the mill is relatively constant and the initial BOD level in the river is essentially a function of the dilution available and the amount of BOD (approximately 1 mg/l) in the upstream water.

Bottom Organisms

An extensive study of the bottom organisms of the river by Scott (5) has shown that the effect on the pollution-sensitive species is of no great magnitude. He further found that there was ample evidence that toxicity was not a factor and that whatever changes occurred were temporary.

Slime Encased Bacteria

With this picture of slight imbalance, some year and a half after the start of mill operation, a serious problem of *Sphaerotilus natans* infestation developed. As with most problems of this type, it showed itself by a covering of the debris and other material in the river with a fur-like coating of

organisms. At points of heavy growth, the *Sphaerotilus* developed into large bulb-like clumps. These growths are obviously objectionable from the aesthetic point of view. In addition, when the *Sphaerotilus* floc develops in size beyond the physical strength of the anchor or when decomposition inside the growth weakens its connection, the floc breaks loose and floats downstream, mechanically attaching itself to anything it encounters. When commercial net-fishing operations are carried on in the area of infestation or downstream from it, the results can be highly undesirable. Figure 2 shows the effect of heavy infestation on a net.

Studies of *Sphaerotilus natans* have been made on numerous occasions, some from the pure bacteriological point of view, others because of its appearance in bulking activated

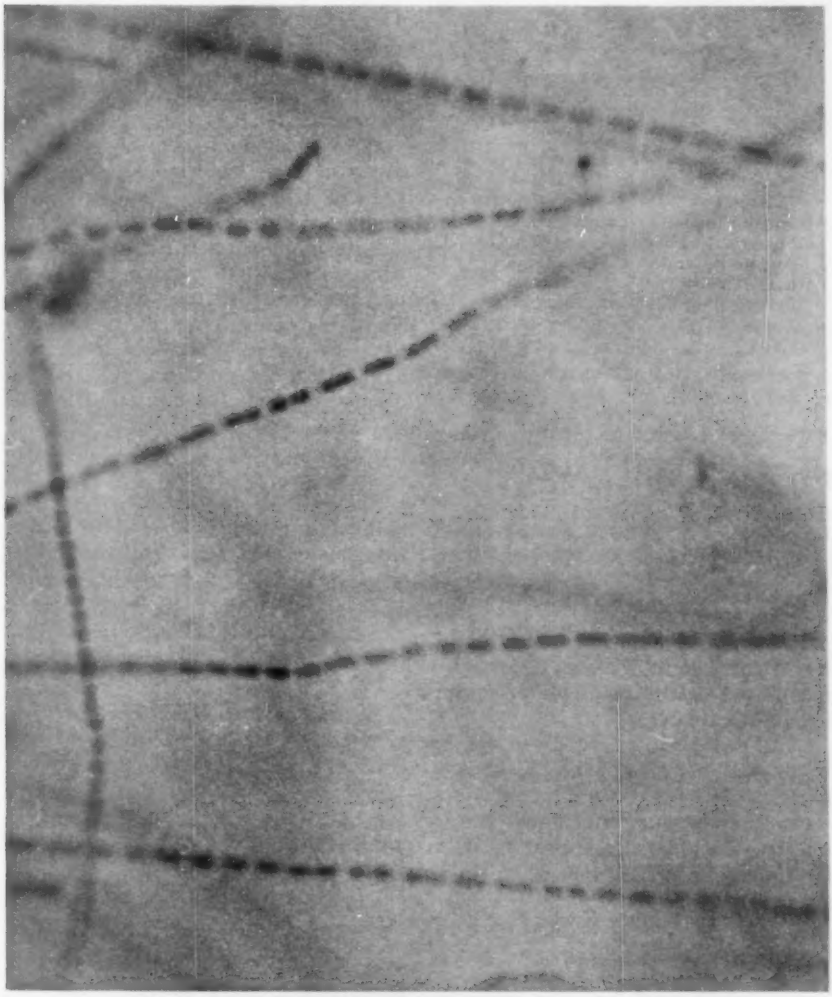

FIGURE 3.—Photomicrograph of *Sphaerotilus*—approx. 320 ×.

sludge, and several in connection with infestations.

Of the many papers written on this organism since it was discovered by Kutzing in 1833, those of most interest from the point of view of *Sphaerotilus'* part in stream imbalance are by Lackey and Wattie (6), Hoehnl (7) (8), Stokes (9), and the literature review prepared from the National Council for Stream Improvement (10). A summary of the reported metabolites is listed below:

Sphaerotilus Metabolites

Glucose	Leucine
Galactose	Glutamic Acid
Fructose	Aspartic Acid
Maltose	Asparagine
Sucrose	Alanine
Sorbitol	Cystine
Mannitol	Tryptophane
Succinic Acid	Arginine
Fumaric Acid	Proline
Sodium Butyrate	Methanol
Lactic Acid	Ethanol
Pyruvic Acid	Butanol
Acetic Acid	Glycerol

Environmental conditions for *Sphaerotilus* development are as follows:

Item	Requirement
pH	6.0–8.0
Temperature (°C)	5–40
DO (mg/l)	3.0 (min)
Nitrogen	Organic source preferred —no data on min requirement
Phosphorus (mg/l)	0.02 (min)

Sphaerotilus natans is a member of the Chlamydobacteriaceae. Normally it is found in a filamentous form with its rod-shaped cells (1 to 2 $\mu \times 3$ to 8 μ) enclosed in a sheath as shown in Figure 3. Reproduction is by binary fission. Although some investigators report fragmentation into motile conidia, this does not appear to be a form of reproduction common in problems associated with pulp mill effluents. Growth usually takes place with one end of the colony anchored while the remainder is suspended in the current. The development of large numbers of colonies which intertwine gives the fur-like appearance of infestations.

Infestations

In problems associated with Kraft process pulp and paper mills, the source of nutrients for the slime development is limited to the black liquor lost in the cooking, screening, and recovery process. In a well-operated mill, this amounts to about 3 per cent of the liquor. Based on Hagglund's (11) analysis of a typical black liquor (Table II), the primary nutrients are formate, methanol, lactate, acetate, and probably some saccharinic acids and lactones.

Pure compound studies made at Jesup of these materials at concentrations of 1 mg/l using simulated river conditions have shown that lactate and acetate will support heavy growth while formate and methanol will support somewhat smaller developments. These materials represent roughly 15 per cent of the total waste load from a mill. In the particular case under discussion about 0.5 mg/l of BOD in the river or 8,000 to 9,000 lb of BOD per day can be attributed to these four compounds.

Sphaerotilus has demonstrated the ability to establish growth in quantity at amazingly low food concentrations. Hoehnl (8) reports growth at 1:1,000,000 dilution of beech liquor which amounts to a sugar concentration of 20 to 50 μg/l. Amberg (12)

TABLE II.—Kraft Black Liquor Analysis as a Fraction of the Weight of the Wood

Item	Per Cent
Cellulose	42.8
Alkali lignin	21.6
Resin, fats, etc.	2.2
Lactones and hydroxy (saccharinic, lactic) acids	18.2
Acetic acid	3.2
Formic acid	1.7
Methyl alcohol	0.4
Lignins soluble in acid solution	6.9

has found that within limits the quantity of growth is independent of the dilution of the food. Extensive studies of activated sludge treatment of the Jesup waste have shown that treatment to effect 90 per cent BOD removal with activated sludge, and subsequent dilution of 100:1 in the stream, still does not prevent *Sphaerotilus* growth. Dilution of the mill effluent to 500:1 at high river stages relieves the problem somewhat but makes only small reductions in the quantity of growth.

Temperature

The environmental condition which has the most pronounced effect on *Sphaerotilus* infestations is the temperature of the river. A definite variation in the extent of the growth area can be seen with variations in temperature. With a relatively constant supply of food, the changes in the rate of metabolisms brought by temperature manifest themselves as an increase or decrease in the extent of growth. During the summer when the temperature of the Altamaha River approaches 30°C the growth (Figure 4) recedes to within 200 yd of the outfall. As the river temperature drops to its usual 10°C winter level, the extent of growth increase is to about 15 miles.

This is a startling effect, particularly when it is considered that the river flow is lower in the summer, thus increasing slightly the concentration of food. However, this 20°C change in temperature results in a four-fold increase in the demands of each organism on the relatively constant nutrient supply, thus decreasing markedly the potential number of organisms.

During the period of abnormally cold river temperature (4°C) of 1957–8, growth almost entirely ceased but recovered with rising temperatures.

Control Procedures—Full Scale

An interesting approach to the control of these infestations is by the use of the method of intermittent discharge developed by Amberg and Elder (13). This method is intended to keep the organism in its lag growth phase by discharging the waste in short periods, thus preventing the development of infestation quantities. Amberg reports that a discharge over

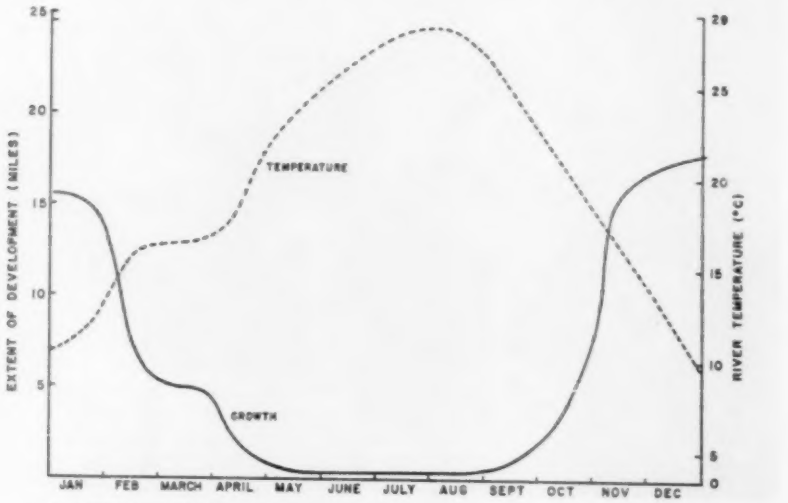

FIGURE 4.—Relation of extent of macroscopic growth of *Sphaerotilus* to river temperature.

a period of two hours in a day will prevent growth development and over a maximum period of six hours in a day will reduce growth. Although the physical facilities did not permit reduction of the discharge period below 8 to 10 hr per day, this method was used with some success on several occasions at Jesup. The first attempts made during the early months of 1957 were timed to begin after mill shutdowns had cleared the river of growth. Three trial runs under these conditions showed that growth could not be prevented but that development to infestation proportions was delayed by two to three weeks. A later trial run when growth was already established in the river showed no discernible reduction. However, in this last run, discharge periods could not be much below 12 hr due to high river stages.

Control Procedures—Laboratory

The effectiveness of other measures for controlling infestation has been assessed, using laboratory methods for simulating river conditions. Figure 5 shows one of the methods used. In these studies the particular material being examined, either a treated effluent, a pure compound for metabolism study, or a mill waste fraction is introduced into a tank, using a metering pump, and mixed with river water for dilution. After several days of operation, the ability of the material to support growth can be estimated from the amount attached to the sides of the tank. Using this equipment, effluent treated by activated sludge, trickling filters, chlorination, lagooning, and by supplementation of inorganic nutrients, has been tested. To date the results have shown that the quantity

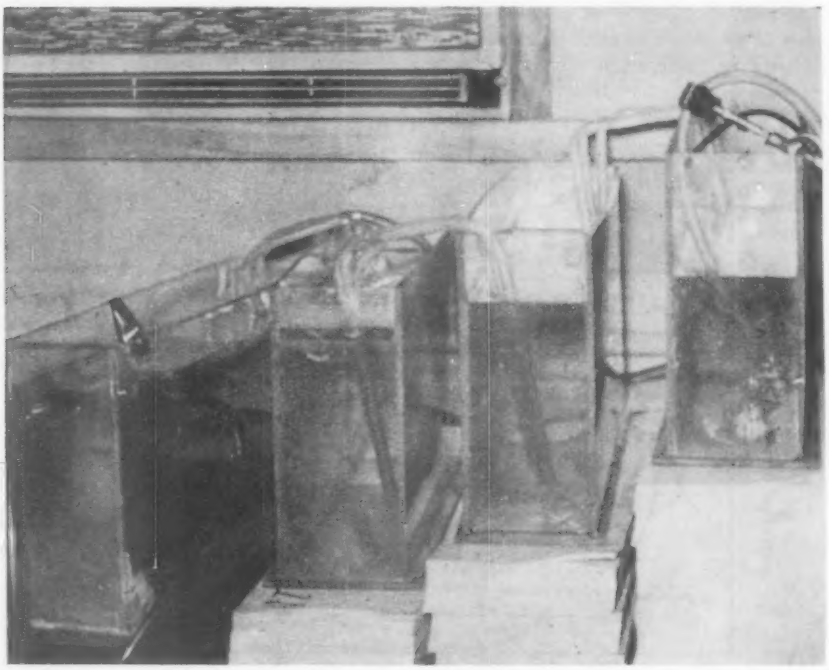

FIGURE 5.—Equipment for simulating river condition used to evaluate waste potential for supporting *Sphaerotilus*.

of growth decreases directly with the reduction in BOD achieved by treatment of the waste before dilution, but that within the limits of conventional biological approaches growth cannot be prevented. Chlorination by itself was not effective in these tests. Nutrient supplementation work continues.

Because of the ability to extract food, the critical factor is not the concentration present but the amount which passes a given point. This situation is supported by the observation that the growth in the river and in experiments at points of high river velocity is maximum. In laboratory scale experiments, the quantity of growth at a given spot can be increased markedly by using a stirrer, thus causing the waste to be recirculated past the point under consideration. In equipment such as shown in Figure 5, the addition of a stirrer will, in a matter of 48 hr, increase the growth from a barely visible degree to a thickness of about one-half inch. In the river, quiescent areas are normally free of any visible growth.

Discussion

Although many years of research have been occupied with studies of *Sphaerotilus*, no completely satisfactory theory has been advanced for the occurrence of infestations. The known environmental conditions are low food concentration, high dissolved oxygen, near neutral pH, low temperature, and sufficient short chain organics (organic compounds) to support the infestation. The particular ability of this organism to extract its food from low concentrations with considerable efficiency is hypothesized as the primary cause for its predominance. However, except for the low food concentration, all of these environmental conditions are those under which almost any aerobe should prosper. Formate, acetate, methanol, and lactate are metabolized by many bacteria common to the soil and water. Unless the ability of *Sphaerotilus* to extract food is unique, which is questionable, it would seem that some other factor is involved.

The colonial form of *Sphaerotilus* is the proximate cause of the mass which makes up the infestation. A *Sphaerotilus* floc contains accumulations of silt, together with a heterogeneous population of organisms. Present are other bacteria, protozoa, algae, and frequently some higher invertebrates. This population is bound together by the gummy filaments of *Sphaerotilus* acting as the binding tape. Numerous solids determinations on flocs collected in the river have shown the volatile fraction to be about 50 per cent. The functional purpose of the sheath and/or the colonial form has been the subject of much discussion but little is actually known regarding the subject. Because of the growth at low food concentration, the possibility that it is a food concentrating mechanism presents itself. This supposition is supported by work with plate cultures grown on nutrient agar. As the concentration of nutrients, both organic and inorganic, is decreased the filamentous forms become more obvious and the sheath thickness increases. Further work is now in progress to determine if the changes in the sheath are a reaction to the lowering of the concentration of an inorganic nutrient or the carbohydrate level. As regulations force industry toward low river food levels the answer to this problem will assume greater importance.

The failure of biological treatment to prevent growth was unexpected. The short chain organics in the waste which support the *Sphaerotilus* should also be rapidly metabolized, either in an activated sludge plant or a trickling filter. It might be expected that partial treatment would result in either prevention or extensive reduction in the growth developed. That this was not true, and the fact that even complete treatment to a highly

polished effluent only reduced the problem, would tend to support the feeling that the ability of *Sphaerotilus* to predominate is strictly a food extraction situation. In these experiments excellent sludges developed and no attempt was made to conserve nitrogen or phosphorus so that the effluent should constitute a balanced diet for the river biota.

The limited success of intermittent discharge to control growth in the full-scale tests can be attributed mainly to the length of the discharge periods used. Amberg's basic data showed reduction in growth with discharge periods of over two hours for experiments of seven days duration. In the full-scale application definite reduction was shown during the first seven days. It was after two to three weeks that growth developed fully. This control measure was developed on the premise that during the discharge period the seed *Sphaerotilus* present would not progress far enough into the lag or possibly log growth phase to prevent their return to an endogenous phase during the waste holding part of the cycle. Discharge for many weeks at an interval greater than the 2-hr period which prevented growth, slowed the development of the seed but did not return it to an endogenous state. In time, full growth developed.

Since the infestation at Jesup did not develop until some year and a half after the start of mill operations, there would appear to be some doubt as to the hypothesis that food level is the cause of the predominance shift. If the further work on this subject indicates that food level is the sole causative agent for *Sphaerotilus* infestation, industries which produce waste containing short chain organics will be faced with a difficult problem if infestations are to be prevented.

Summary

Biological imbalance caused by the addition of substantial amounts of waste to streams offering high dilution in the presence of sufficient dissolved oxygen, short chain organic compounds, near neutral pH, and other known and unknown environmental conditions, causes infestations of *Sphaerotilus natans*. These infestations are markedly affected by temperature conditions, less drastically by variations in the dilution, and can be reduced but not prevented by conventional BOD reduction measures.

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THE OPERATOR'S CORNER

INTERPRETING LABORATORY OPERATING DATA *

By Robert E. Leaver

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How many operators are making maximum use of their laboratory work and records? How many occasionally sit down and summarize their annual reports and see if they can obtain additional information and learn lessons that are not self-evident from the day to day operation? Probably not very many.

To illustrate the type of information that may be obtained from monthly operating reports, the following discussion is based on a summary of the monthly reports from the City of Vancouver (Wash.) sewage treatment plant for 1956 (Table I).

The report and operation of the Vancouver plant, being exceptionally good, were readily adaptable to analysis and study for laboratory control.

General Data

Flow

The average flow per capita based on a connected population of 30,000 is 77 gpd. Compare this with the average city water use in 1953 of 108 gpd/cap, or 80 gpd/cap in winter and 140 gpd/cap in the summer. Although these flow data are of value for plant operation, they do not show the sewage overflow to the river. Hence, special studies would be necessary to determine the seriousness of this problem. Up-to-date water consumption rates plotted against sewage flow, and in light of the rainfall curve, would be of real value in studying infiltration problems. It would be possible to determine the quantity of untreated overflow.

Temperature

The average temperature of Vancouver sewage for 1956 was 63°F. The average yearly temperature during 1949 for all plants reporting in western Washington was 57°F, and in eastern Washington 58°F. Hence, it would appear that Vancouver has considerably warmer sewage than other towns. Is this due to unusually warm industrial wastes or less infiltration? A little investigation and summary for other years, considering the mean air temperatures, might lead to some interesting observations.

Grit

The average of 1.0 cu ft of grit removed per day for 30,000 population is high for a purely domestic sewage. However, it is about what would be expected in Vancouver where some combined sewers still exist. Regardless of original expectations, grit chambers have, in general, been a necessity at certain times.

* Presented at the 1957 Annual Meeting, Pacific Northwest Sewage and Industrial Wastes Assn.; Seattle, Wash.; Oct. 24–26, 1957.

TABLE I.—Summary of Monthly Operating Data for the Vancouver, Wash., Sewage Treatment Plant for 1956 *

Item	Monthly Average												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Avg
Flow (mgd):													
Avg	2.3	2.5	2.5	2.4	2.7	2.7	2.1	2.3	2.0	2.0	1.8	1.8	2.3
Max	6.3	6.9	7.1	7.2	6.9	6.8	3.7	5.6	5.7	6.8	6.0	5.8	7.2
Min	0.5	0.9	0.8	1.0	0.4	1.0	0.3	0.7	0.4	0.2	0.4	0.3	0.2
Temp (°F):													
Avg	55	58	60	62	65+	64	68	68	67	65	62	61	63
Max	64	59	62	67	70	69	71	73	73	69	67	64	73
Min	46	52	49	58	62	61	64	65	64	60	56	56	49
Grit (cu ft/day)	1.8	0.7	1.3	0.7	0.8	0.9	0.4	0.9	1.4	1.4	0.9	1.0	1.0
Settleable solids (ml/l):													
Infl.	8	10	9	9	8	8	9	8	9	9	10	11	9
Effl.	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr
DO (ppm):													
Infl.	3.2	3.3	3.5	3.0	2.3	2.0	1.7	2.3	2.8	3.1	2.7	1.5	2.6
Effl.	2.8	2.8	3.0	2.6	1.9	1.6	1.6	2.3	2.4	2.8	2.4	1.3	2.3
pH:													
Infl.	7.9	7.6	7.6	7.6	7.4	7.4	7.6	7.4	7.8	7.6	7.4	7.7	7.6
Effl.	7.7	7.4	7.4	7.3	7.3	7.2	7.3	7.3	7.4	7.4	7.5	7.6	7.4
Sludge digestion:													
Temp, No. 1 (°F)	92	101	96	101	105	104	106	105	107	105	107	108	100
Temp, No. 2 (°F)	82	89	87	91	96	94	98	98	99	99	93	95	93
pH, No. 1	6.9	6.7	7.1	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	6.9
pH, No. 2	7.1	6.9	7.1	7.1	7.1	7.0	7.0	7.0	7.1	7.0	7.0	7.0	7.0
Gas (1,000 cu ft/day)	12	20.4	25	23.6	21.7	14.8	17.9	18.6	21.8	18.5	20.4	18	19.4
Sludge pumped (gpd)	5,715	5,600	5,362	5,422	6,010	5,000	5,851	6,176	5,943	5,558	5,374	5,440	5,600
Sludge withdrawn (gal)	—	—	—	—	—	18,720	53,486	28,238	15,345	40,507	21,802	21,875	—
Sludge solids (%):													
Raw	7.0	7.0	8.1	7.2	7.8	7.0	7.0	7.0	6.8	7.0	6.6	7.4	7.2
Digested	—	—	—	—	—	11.2	12.0	9.3	12.5	12.1	9.6	9.3	10.8
Volatile solids (%):													
Raw	67	69	66	69	67	67	71	68	72	70	74	68	70
Digested	—	—	—	—	—	35	37.8	39.4	38.2	37.4	41.1	43.2	39
Chlorination:													
Pre- (lb/day)	0	0	0	81	0	0	0	0	0	0	0	0	—
Post- (lb/day)	88–12	108	105	0	84	71–13	86	87	77	73	69	42	81
Residual (ppm)	0	—	—	—	—	—	0.5	—	0.4	0.2	0.3	0.1	—
Lime (lb)	1,000	0	0	0	0	0	0	0	0	0	0	0	—
Costs ($):													
Power	85	86	83	94	182	218	83	58	60	67	78	76	98
Chlorine	80	235	228	183	195	70	194	230	161	158	142	128	166
Labor	1,313	1,236	1,363	1,388	1,440	1,414	1,254	1,347	1,207	1,173	1,235	1,212	1,290
Misc.	27	420	271	153	56	22	33	35	135	78	64	41	111
Income	105	37	195	718	200	104	105	81	101	86	77	42	154
Total	1,400	1,940	1,750	1,100	1,673	1,620	1,459	1,589	1,462	1,390	1,442	1,415	1,510

* Connected population, approximately 30,000.

Sewage Characteristics

Settleable Solids

The average of 9 ml/l for raw sewage is very high for plants in Washington. The range usually runs from 1.0 to 6.0 ml/l.

To estimate the number of gallons per day of settleable solids produced, multiply settleable solids content in ml/l times flow in mgd times 1,000. In the case of Vancouver this is equal to $9 \times 2.3 \times 1{,}000$, or 20,700 gpd. The collecting mechanism can be expected to concentrate the sludge more than an Imhoff cone and a concentration of 2 to 1 often occurs.. The amount of sludge actually pumped was 5,700 gpd. This represents a concentration of 3.7 to 1. This seems high and makes it appear that the average settleable solids value of 9 ml/l is too large. A few days of sampling through a 24-hr period should establish a time for daily settleable solids sampling that will give results approximating the true average. The effluent should not have over 0.3 ml of settleable solids at any time, if the settling unit is operating right.

Dissolved Oxygen

The dissolved oxygen summary for Vancouver shows only a slight problem during May, June, July, and December. The summer drop of dissolved oxygen is readily explained as a result of higher temperatures. The December drop is no doubt due to low flow.

pH

The pH tests for Vancouver show a typical normal pattern, except for the months of April, July, and September when the average drop across the settling unit is more than 0.2. The reason for this drop is not self-evident. The lack of significance in pH drops, where the pH of the raw sewage is 7.6 or higher, has been noted at many plants.

Digester Operation

Temperatures

The temperatures of the Vancouver digesters are within the normal range for heated units. It is noted that no auxiliary fuel was necessary. Any mistake or trouble in operation during the winter in Washington often results in a cold digester or the need for auxiliary fuel. Plants of less than 5,000 contributing population cannot expect to heat digesters all year without auxiliary fuel.

pH

The pH record for the heated digesters shows they were well within the acceptable maximum methane range. In fact, the pH range is slightly higher than other plants in Washington.

Gas Production

The average gas production was 0.65 cfd/cap, which is about average for primary plants in Washington. The gas production was 11 cu ft per pound of volatile matter destroyed. This is slightly lower than some other plants.

Sludge Characteristics

Gallons Pumped

The gallons of sludge pumped daily do not check with the settleable solids test and the average flow. If a 2 to 1 concentration over Imhoff cone resulted in collection of sludge, the theoretical settleable solids would be 4.9 ml/l.

Per Cent Solids-Raw Sludge

The raw sludge pumped is exceedingly high in solids as compared with other plants. Over 4 per cent solids is considered to be well-concentrated raw sludge. Vancouver raw sludge averaged 7.2 per cent solids.

Per Cent Volatile-Raw Sludge

The volatile solids content of the raw sludge is 70 per cent. This is higher than normal. Average would be 60 per cent.

Sludge Withdrawn

Vancouver withdrew, to covered drying beds, 199,973 gal of (10.8 per cent solids) sludge during 1956. Approximately 2,024,000 gal of (7.2 per cent solids) raw sludge were pumped to the digester.

Per Cent Digested

Vancouver does an excellent job of reducing the volatile matter during digestion. The calculated solids reduction is 72.6 per cent. A heated digester should average at least 60 per cent.

Chlorination

It is obvious from the yearly summary that the amount of chlorine added to the effluent was not sufficient to produce an adequate residual at all times. The average feed was 35 lb per million gallons.

Operating Costs

The 1956 cost of treating Vancouver sewage was approximately $21.70 per million gallons. The income from selling sludge and handling septic tank cleanings averaged $154 a month.

Conclusion

Although official agencies can be helpful, the real value of reports and laboratory work depends almost entirely on the intelligence and degree of use the operator puts into making the report and interpreting it.

COMBINED TREATMENT OF POULTRY AND DOMESTIC WASTES*

By J. M. Roberts

Vice-President, Robert and Company Associates, Atlanta, Ga.

It has been in comparatively recent years that poultry raising, processing, marketing, and distribution operations have become centralized in this as well as other areas.

The Georgia poultry industry located mainly in the northeast Georgia area began about 1935 and at present contains eight major plants in one small locality that process 270,000 birds daily, with peak handling of 330,000.

The industry as a rule functions about as follows:

1. The processor furnishes baby chicks and feed to the grower.
2. After about six weeks the grower sends the broilers to the processor.
3. The broilers are processed, prepared, and marketed by the processor.

Wastes from Processing

The waste contributed by the processing constitutes the bulk of liquid waste for treatment and eventual disposal to the streams. Hatcheries have a shell disposal problem usually resolved by separating and hauling the shell sand (finely ground shells). This material is an excellent source of limestone for soil conditioning.

Broilers are delivered by truck to the plants and are hung live by their feet on a moving chain, which delivers them to the killing position where the throat is slit and blood flows into a trough which connects to drums for storage. In some plants the blood is sprayed with a coagulant and the residue shoveled into drums with the supernatant going to the sewers. The chain continues through the plant and the birds are mechanically picked, washed, cleaned, washed again, and finally removed from the chain. At strategic locations along the chain, drums are provided for storing feathers, offal, heads, feet, and other scrap and waste products. The dressed bird goes to the process that is being practiced on that day, i.e., freezing, cutting, refrigeration, or other. Plants that are subject to federal government inspection have a "flow-away system," where offal, heads, feet, etc., flow in a flume to a central screening station. Residue removed by the screen is placed in drums and sent to rendering plants while the liquid is recirculated through the "flow-away" flumes. The overflow goes to the sewer.

Rendering plants in the area offer a ready market for offal, feet, heads, scraps, etc., to be converted to tankage and used as a feed additive or processed as pet food or fertilizer. In spite of this apparent profitable means of disposal, a large percentage of this material finds its way into the sewers.

* Presented at Industrial Waste Conference, Georgia Institute of Technology; Atlanta, Ga.; Apr. 11, 1958.

TABLE I.—Liquid Poultry Waste Characteristics from Gainesville, Ga.

Sample	Total Solids (ppm)	Suspended Solids (ppm)	Settleable Solids (ppm)	Grease (ppm)	BOD (ppm)
Half poultry waste + half domestic sewage	698	478	378	85	780
Poultry waste	981	564	346	49	1,100
Composite 24-hr mixed sample	691	228	170	56	510

Samples taken from sewers near processing plants indicated characteristics as shown in Table I.

The number of birds being processed when the data shown in Table I were collected is not known; however, additional information obtained at a later date for a weeks operation is as follows:

No. of Birds Processed	Total Water Used (mil gal)	Unit Water Used (gal per bird)
815,000	2.66	3.26

The water used per bird averaged 5.32 gal in the government inspected plants and only 2.17 gal in the other plants. By assuming from Table I that the BOD equals 1,100 ppm, then the BOD contributed per bird amounts to 0.03 lb.

By accepting 0.17 lb BOD per person per day as a normal sewage contribution, then each six birds processed equals one person. In plants where no attempt is made to recover offal, etc., this BOD loading would be much greater.

On the basis of 3.26 gal of water per bird and the analysis of 100 per cent waste, composition of the waste to be expected from a processing plant per 1,000 birds is about as follows:

Item	Lb per 1,000 birds
Total solids	26.6
Suspended solids	15.3
Settleable solids	9.4
Grease	1.3
5-Day BOD	30.0

The waste should, and does, respond readily to biological treatment, and if troublesome materials such as feathers, feet, heads, etc. are removed no particular troubles are experienced.

Combined Treatment Plant

Prior to 1949 the sewerage system at Gainesville consisted of a series of outfalls and laterals piped to the nearest point of natural drainage. The rapid growth of the poultry industry and shifting of their operations to more spacious areas made it mandatory that something be done to relieve the rapid deterioration of one stream receiving a large part of the untreated poultry waste. As a result the sewage and waste in this particular drainage area were collected in a new outfall and pumped to the Chattahoochee drainage area. Further growth has caused this outfall now to be near capacity.

A large dam project, with its attendant reservoir, subsequently became a certainty and was responsible for plans to collect and treat all sewage and waste in a common plant. Due to the large lake that would receive the treated waste, a plant designed for 80 to 85 per cent suspended solids and 60 to 65 per cent BOD removal was considered adequate. The combined raw waste for design purposes was considered to have a suspended solids content of approximately 500 ppm and an equal amount of 5-day BOD. The plant site selected was about one and a half miles downstream from the water intake, and by considering the operation of the reservoir and the large volume of the receiving water this distance was considered satisfactory.

The poultry process waste is pumped from the drainage area, where it is produced, into an outfall that connects to an interceptor along the shore of the lake; just before reaching the plant a low head pumping station lifts the combined sewage and poultry waste to the plant. The first pumping station is equipped with a comminutor for grinding offal, etc., but experience has shown that due to surges and unexpected high flow the unit often overflows and waste by-passes the comminutor, which allows considerable scraps, heads, feet, etc. to get to the plant.

Operation

Due to the rapid growth of the poultry industry the high-rate trickling filter plant within a year approached its design capacity, which

was 2.5 mgd with a population equivalent of 80,000 (on a BOD basis).

Other factors of interest during the first year of operation are as follows:

Operation or Determination	Amount or Degree
Average grit removal daily	9.95 cu ft
Average feathers removed daily	16.38 cu ft
Range of BOD removal	60–65%
Range of settleable solids removal	85–97%
Range of suspended solids removal	80–85%

An ordinance was passed during 1957 requiring all processors to install, operate, and maintain satisfactory screening installations whereby a 20-mesh screen would satisfactorily handle all waste without any by-passing or overflowing. This requirement has reduced the volume of grit and feathers reaching the treatment plant.

A comparison of grit and feathers for the first and last half of 1957 is as follows:

Grit and Feathers	First 6 Months	Last 6 Months
Grit, avg cfd	10.38	9.50
Feathers, avg cfd	20.20	12.81

It is estimated that at the end of the year some 50 to 60 per cent of the poultry waste was being screened. After complete installation of all screening stations it is expected that feather content will be further reduced. All of the grit cannot be attributed to the poultry waste since it is known that a part of the domestic waste sewer system has considerable infiltration.

Screening stations being installed consist principally of 2 types, vibrating or rotary. Of the two types the vibrating screen seems to be somewhat more effective, but in any installation it must be carefully engineered to have ample capacity, to prevent any by-passing, and to assure overflow return to the influent.

Operational Problems

Soon after initial operation it was determined that the problems related to handling and treating this waste were largely mechanical.

Feathers

Feathers were particularly troublesome and on occasion approximately 25 to 30 cfd collected as a heavy mat floating in the wet well of the pumping station. Others were carried through the pumps to the treatment plant where some were removed by a mechanical rake on a bar screen. The hammer-mill type grinder which is normally used for sewage solids could easily be stalled with feathers; the feathers matted and wedged, causing the grinder to overload and stall. Experience showed that with slower and more careful feeding into the grinder frequency of stalling could be greatly reduced. Some feathers get by the screening and grinding installation but are not particularly troublesome in the plant. Rotary distributors on the filters require more than normal flushing and orifice cleaning, but the high rate of flow through the distributors, requiring a larger orifice, is of considerable relief in this connection.

Pumping

Possibly the most difficult mechanical problem is the pumping of primary sludge with double plunger pumps. Most of these unusual maintenance and operational pumping problems are caused by chicken heads and feet, particularly the heads, since a chicken head is ideally shaped to start under a ball valve but just a little too large to go all the way through. Frequent stoppages and dismantlings are the result.

Solids and Digestion

An unusual characteristic of poultry waste is the specific gravity. It cannot be predicted whether feathers, offal, etc. will float or sink. In some instances a majority seems to be removed from the bottom of the primary tanks, while on other occasions a majority seems to be removed by skimming.

Due to high solids content of the

combined waste, digesters were filled rapidly which caused some trouble in initial operation. Heat was controlled from the beginning, which started early gas production, but the quality was poor and the pH was low. By allowing one digester to rest, maintaining careful sludge feeding to the other, and drawing sludge as frequently as possible, operation was maintained at about normal. About 10,000 cu ft of well-digested sludge was produced and dried during 1957.

Inspection of dried sludge indicated no evidence of undigested feathers and there has been no apparent formation of a feather mat on the digester surface. Almost continual recirculation of warm sludge to the top of the digesters possibly tends to prevent serious mat formation.

Suggested Improvements

Design and operation of a plant treating poultry wastes requires care and ingenuity on the part of both designer and operator and, in addition, utmost cooperation of the waste-producing industry. Mechanical features that might be an improvement include (a) the use of a cutter type grinder which is considerably overpowered, rather than the hammer mill type and (b) the use of one of the newer type sludge pumps for primary sludge. The installation of one large screening and grinding station rather than a smaller unit at each plant might be more practical, but the problem of such a large volume of solids in the sewage collection system from the poultry plants to the screening station would likely cause untold problems of stoppage, overflowing, etc., not to mention the increased cost of the sewers to allow for the large volume of feathers.

Treatment Costs

The operation of the Gainesville plant compares favorably with operation of similar plants. During the year 1957 the average cost of treating, pumping, etc., was $42.62 per million gallons or $.017 per lb of BOD removed.

The poultry industry is of untold economic value to this area, in that it provides employment and livelihood to many people directly and through related industries. City officials were fully cognizant of this fact, but it was necessary that the cost of constructing and operating a system be proportioned as fairly as possible among the users. The city does not have a city-wide sewer service charge but the water rates were established to provide revenue for financing and operating both the water and sewer systems. These rates vary from $0.45 per 100 cu ft per month for the first 4,000 cu ft to $0.18 per 100 cu ft for amounts in excess of 112,000 cu ft.

These rates result in a plant that uses 2.0 mil gal per day or 267,000 cfd having a water bill of $535.00 or and average of $0.267 per thousand gallons or $0.20 per 100 cu ft.

Due to the additional load caused by the industry, a sewer charge, or license fee, of $100 per month is made to each plant. At first this charge was made on a basis of $0.15 per 1,000 birds processed per month, but due to difficulty of accurate billing this plan was abandoned in favor of the simpler method.

Summary

In summary, it may be established that poultry processing wastes may be successfully treated by biological process, if careful design and operation are practiced. Special attention should be given to mechanical features to adequately transfer the solid content peculiar to the waste.

There is every reason to believe that this waste could be treated just as successfully separately, as in combination with domestic sewage, by making the proper adjustments in plant design and features.

INTERESTING EXTRACTS FROM OPERATION REPORTS

"The best place to look for a helping hand is at the end of your arm."—*Anon.*

Attention operators! It will be appreciated if copies of all annual reports of both large and small sewage and industrial waste treatment plants are sent to the Federation office for abstracting in this section of the Journal. Please direct annual reports to: The Operator's Corner, Federation of Sewage and Industrial Wastes Associations, 4435 Wisconsin Ave., N.W., Washington 16, D. C.

Annual Reports of the Detroit, Mich., Sewage Treatment Plant for the Fiscal Years, 1956 and 1957 *

FRED. H. BURLEY, *Engineer of Sewage Treatment*

Sewage and the greater portion of storm water from Detroit and 35 suburban areas are transmitted to the sewage treatment plant through two large diameter interceptors. A lift of approximately 30 ft at the plant permits gravity flow through the bar racks, grit chambers, sedimentation tanks, and chlorination chamber. Chlorine contact time is equal to the time of passage of plant effluent through an 18-ft diameter, 6,000-ft long outfall discharging to the Detroit River. Raw sludge is dewatered on vacuum filters and incinerated. About one-fourth of the sludge is partially reduced in a single digester. Total pumpage continues to increase, with 187,180 mil gal being pumped during 1957. A new daily high of 912 mil gal was also established in 1957.

The biweekly practice of pumping the suction well 10 ft below normal levels to create scouring velocities in the interceptors was continued. The suction well was inspected daily and large floating material removed.

Weekly sampling of the Detroit and lower Rouge Rivers was continued to determine the effect of plant effluent on these watercourses. Special river investigations were carried on as the need developed. Monthly checks were made on the operation of regulators, backwater gates, and dams. River front storm sewer outlets were inspected by boat during warm weather.

Both ash lagoons required cleaning during 1957, and contracts were let for the removal of 100,325 cu yd of ash. The two ash lines, each about 1,000 ft long, are checked yearly for calcium deposits. In November 1956 cleaning became necessary. This was done by cycling 10,400 gal of muriatic acid solution through the lines.

Expansion and Improvements

Two new sedimentation tanks were placed in operation during July 1956. Sand-laden sludge deposited in the sedimentation tanks during heavy storm flows reduced the discharge of the bladeless impeller sludge pumps, making continuous operation necessary. Three of the pumps were equipped with larger 1,750-rpm motors. This change has largely overcome sludge delivery difficulties. In May 1957 a vortex-type pump was installed. At the original impeller speed it failed to deliver heavy sludge. When the speed was increased to 1,150 rpm it delivered a satisfactory volume, but rapid wearing of the suction housing

* For last previous extract see THIS JOURNAL, **29**, 1, 99 (Jan. 1957).

was observed. Further study of this type of pump will be necessary.

Two main sewage pumps, each of 230 cfs capacity, were installed and tested in December 1956. Installed pumping capacity now totals 1,188 mgd. Four 500-sq ft, rotary vacuum filters were placed in operation during December 1955. This addition brings to 12 the number of filters installed and increases the filter area to 6,000 sq ft. Bar racks and grit collector equipment for two existing grit chambers, built as part of the original rack and grit building, were installed by plant maintenance forces and placed in operation during January 1957.

Solids Removal

Screenings removed by the bar racks are ground and returned to the sewage flow. Wood, metal, rags, and other debris are removed manually from the conveyor and hauled to city incinerators. The 150-hp motor on the screening grinder failed after approximately 16½ yr of service and was replaced with the spare ash pump motor.

Grit removal continued to increase and totalled 23,479 tons (wet basis) during 1956 and 26,712 tons during 1957. During and after very heavy storms grit was removed faster than it could be stored or incinerated. Nine times during 1956–57 excess grit was diverted to the ash lagoons.

During 1957 the 10 sedimentation tanks functioned satisfactorily, removing 103,047 tons (dry basis) of suspended solids and 36,660 tons of BOD. The addition of the two new tanks increased the number in service from 7.4 to 8.7 units, increased the detention time from 1.08 to 1.18 hr, the suspended solids removal from 48.1 to 53.0 per cent, and the suspended solids removal per million gallons from 0.46 to 0.55 tons.

Grease and scum removal increased from 1,829 tons in 1956 to 2,343 tons (wet basis) in 1957. These skimmings are disposed of by placing small quantities on the lower hearths of one of the incinerators.

The practice of stopping the main sludge collectors during and after heavy storms to relieve overloading of the cross collector was discontinued, except for extreme cases. While collector shutdown relieved the strain on the cross collectors it permitted heavy material to concentrate in front of the main collectors and overload them. Reversal and replacement of collector chains were carried out as required.

More rapid deposition of hard grease in the sludge header and sludge lines was attributed to increased quantities of ground garbage. Piping was arranged to permit softening of the grease using warm digester sludge. Lines were flushed with a large capacity sludge pump.

Digestion

Digester operation was normal except for two periods in February 1957, when gas production declined nearly 50 per cent. Feeding was reduced to rest the digester and allow tank temperature to rise to normal. Sludge filtration was also poor during this period, but laboratory tests failed to show the presence of inhibitory wastes. The biannual tank inspection and descaling of the heating coil were completed in August 1955. The alarm system installed in 1950 for odorizing digester gas again proved valuable in locating leaks.

Sludge Filtration

Sludge conditioned and filtered totalled 64,839 and 66,260 tons (dry basis) for 1956 and 1957, respectively. Of the totals, approximately 97 per cent was conditioned with ferric chloride and lime and approximately 3 per cent with lime only. For several years the dosage of ferric chloride has been on the increase, reflecting the general change in the characteristics of the settled sludge. A waste slurry from

TABLE I.—Summary of Operating Data at Detroit, Mich., for Fiscal Years 1956 and 1957

Item	1956	1957
Rainfall, total (in.)	33.3	34.9
Estimated connected pop.	2,600,000	2,628,000
Sewage pumped (mgd)	475	513
Solids removed:		
Grit, dry (tons)	12,123	14,625
Tank scum (tons):		
Dry	1,189	1,523
Volatile	1,070	1,369
Susp. solids (tons):		
Dry	79,950	103,047
Volatile	48,897	64,315
Total solids (tons):		
Dry	93,262	119,195
Volatile	53,600	70,001
Analytical data:		
Susp. solids:		
Influent (ppm)	225	245
Effluent (ppm)	115	115
Reduction (%)	48	53
BOD:		
Influent (ppm)	120	130
Effluent (ppm)	83	85
Reduction (%)	31	35
Grit (%):		
Solids	52	55
Volatile	30	30
Raw sludge to digester (%):		
Total solids	9.5	9.9
Volatile solids	58	59
Sludge digestion:		
Total added (mil gal)	27.5	26.7
Dry solids added (tons)	10,832	11,119
Dry solids withdrawn (tons)	7,031	10,505
Supernatant (%):		
Solids	5.4	6.2
Volatile solids	48	48
Gas production:		
1,000 cu ft	72,775	83,625
Cu ft per lb vol. sol. added	5.85	6.35
Sludge filtered:		
Total (mil gal)	158	150
Dry solids (tons)	64,839	66,250
Solids (%)	10.1	10.4
Volatile solids (%)	52	58
Filter yield (lb/sq ft/hr)	3.9	3.4
Sludge cake, filtered (%):		
Solids	35	35
Volatile	52	54
Incineration:		
Wet (tons)	229,216	241,653
Dry (tons)	84,290	90,494
Wet feed rate (tons/hr/incin.)	8.7	9.2
Fuel oil per wet ton burned (gal)	0.206	0.064
Chlorination (ppm):		
Demand	4.7	4.7
Applied	4.0	4.0

acetylene manufacture successfully served again as the main source of calcium oxide. Filtering a mixture of raw and digested sludge occasionally was found to be advantageous during the winter months, when raw sludge has a gelatinous texture and resists filtration. After 17 years the decking on No. 6 filter required replacement because of decay.

Incineration

The three incinerators were in continuous operation, except for negligible outage time for minor maintenance. Three conveyor belts were replaced after 37,260, 43,028, and 50,000 hr of operation, respectively. A small number of outer and rabble teeth were replaced. A "refractory gun" was used to replace small sections of central shaft insulation.

Chlorination

Chlorine dosage was selected on the basis of the demand of the plant effluent. Satisfactory coliform kills were obtained with dosages ranging from 80 to 100 per cent of the demand. Experience has shown, however, that demands of 3 ppm or less normally require dosages equal to 100 per cent of the demand.

Laboratory

In addition to supplying data for plant control the laboratory operates all chlorination equipment, performs special investigations and research, and is concerned with all aspects of plant safety. Certain industrial waste components—iron, cyanide, and phenol—are determined routinely.

Through a cooperative program with the Department of Public Works the quantity of chlorine-consuming industrial wastes reaching the plant has shown a steady decrease. Ferrous iron in the plant effluent during 1957 averaged 0.22 ppm, as compared to 0.39 ppm in 1956. Cyanide dropped from 0.26 ppm in 1956 to 0.20 ppm in 1957. Phenols increased over the past two years and now averaged 75 ppb. During 1957 the theoretical saving in chlorine required to combine with these wastes amounted to $10,400 as compared with 1956, and considerably greater than that figure when compared with earlier years.

The effects on sludge dewatering of substances such as thawing salt, grease, finely divided clay, and paper pulp were studied in an effort to find the cause of low filter yield during cold weather. Salt was found to exert little effect even in the relatively heavy con-

TABLE II.—Summary of Operating Expenses, Detroit, Mich., Fiscal Years 1956 and 1957

Item	1956*	1957*
General plant	$195,698.96	$207,293.73
Pumping station	247,724.86	272,122.34
Bar rack and grit removal	59,112.94	81,872.42
Sedimentation	68,570.30	122,820.35
Chlorination	231,958.70	256,676.41
Digestion	4,323.41	7,405.70
Filtration and chemicals	221,932.14	251,925.22
Incineration and ash handling	382,154.02	413,306.31
Boiler plant	63,788.11	62,802.70
Interceptors	141,548.95	37,793.01
Sanitary sewage pump station	218,000.00	236,109.34
Miscellaneous	93,957.32	92,427.64
Administration	105,620.08	125,839.78
Depreciation	589,316.83	671,117.00
Total	$2,623,706.62	$2,839,511.95

* Fiscal year ended June 30.

centrations present during the winter. Grease and especially finely divided particles of clay or silt caused clogging of the filter cloth. Paper pulp prevented good adhesion of the sludge to the filter surface. Five commercial flocculating agents and a sample of waste ferric hydroxide were tested as possible process aids. None of these materials had more than a minor effect and their use was not economically justified.

Miscellaneous

Garbage grinding by the Department of Public Works continued on an experimental basis. A 100-ton/day rate was in effect for approximately 3½ months during 1957. The term "garbage" has been applied to alley pickup, which includes paper, cellophane, wooden boxes, feathers, etc. Greater selectivity has been requested to alleviate overload and plugged conditions at the treatment plant.

Personnel were again given the opportunity to receive an annual chest x-ray and typhoid immunization. Employees in close contract with sewage are provided with suitable work clothing.

Table I summarizes fiscal 1955–57 operating data and Table II summarizes operating expenses.

MECHANICAL MAINTENANCE PROGRAM

By R. C. Thayer

Director of Operations, Hampton Roads Sanitation District Commission, Hampton Roads, Va.

Mechanical maintenance in the sewage field can be compared to a man rowing upstream on a fast flowing river—if he stops rowing, he is soon back where he started or worse. Also, like housekeeping, it rarely is obvious until neglected.

Successful mechanical maintenance depends largely on knowledge, persistent hard work, and a sincere interest. Knowledge is gained by experience but, as a starter, the prompt securing and studying of manufacturer's maintenance, lubrication and operating instructions, sectional drawings, and parts lists is invaluable. Studying current trade literature of the field is constantly refreshing and is a flowing fountain of ideas. Leadership should encourage personnel not to be afraid to try new ideas or modifications of equipment or processes where the risk is favorable and good judgment is exercised.

Suggested Practices

Records and Lubrication

Routine maintenance and lubrication are best handled by one man per installation to clarify responsibility and to eliminate confusion and oversight. Use of a simple "repair request" slip initiated by operating personnel clarifies handling in larger organizations. A permanent "maintenance record card" for each major piece of equipment is simple but valuable. A complicated records system is defeated before it is started.

Initial lubrication requirements are best served by contracting with a recognized oil company for products. This should result in an expert survey of the installation and a thoroughly planned program. Experience will then allow for some variation. A thought to remember is that more bearings are lost through overlubrication

than underlubrication. Proper lubrication is important. Proper procedures should be followed.

Metal Spraying

One of the greatest boons to maintenance men has been the expanded use of metallizing or metal spraying. Many shops have the equipment. It is commonly used for quick rebuilding of worn pump shaft sleeves, shaft bearing surfaces, etc. Metal in wire form is drawn through a gun, melted in a oxygen-gas flame, and atomized by a blast of compressed air onto the shaft being rotated in a lathe. A molybdenum alloy with a hardness of 350 Brinnell will give three to four times the life of the standard wearing sleeve material (which often is one of the stainless steels of approximately 200 Brinnell hardness). This alloy cannot be worked with a lathe tool, but must be ground to finished diameters.

Centrifugal Pumps

Centrifugal pumps are common items in the maintenance program. Packing should rarely be added to but rather should be completely replaced. One costly repair to a wearing sleeve will pay for many sets of packing. Shaft wear and dislocation of the lantern ring are inevitable with the practice of adding rings, and result in the necessity for tighter gland pull down. Such abuse indicates laziness.

A soft, square braided, graphite impregnated, asbestos packing is least abusive to shafts. Close impeller wearing ring clearance must be maintained for good efficiency. In design, sewage pump speeds of less than 1,000 rpm are best for extended use where head requirements allow. Use of ¾- to 1¼-in. plastic hose for pump air bleeds (discharging back to wet well or float tube) will eliminate many lost prime problems. A small but vital item is to retain the shaft water slinger ring to protect the adjacent bearing.

Sludge Pumps

Piston sludge pumps give much longer life when crosshead guides are added. A slight trickle of water applied at the pump gland when running will increase sealing and extend packing life. If duplex pumps are disassembled, care must be used not to reverse the eccentrics on reassembly and thereby get the pistons out of step. For sludge circulation, so-called "bladeless" and "torque flow" pumps are very dependable. The latter is definitely becoming a popular choice for digester dewatering service due to its pronounced non-clog characteristic, plus an ability to maintain a high vacuum on the suction. High maintenance costs on heavy duty type sump pumps can be overcome by replacement with small 2-in. electric driven diaphragm pumps.

Chains

In rectangular sludge collectors, it is often overlooked that both chain and sprockets can be turned over when worn. Pintle chain and sprockets are interchangeable among manufacturers and at replacement time, considerable saving may be effected by competitive bidding. Split construction sprockets are good investments, due to labor saving at replacement time. In chain, "tee" head pins with bronze cotters are preferable. Chain with ultimate strength of 27,500 lb and Brinnell hardness of 170 to 190 is adequate for up to 150-ft basin lengths. Idler sprockets can be readily rebabbitted. A tooth height of 60 to 100 per cent of chain barrel diameter should be used. The greatest chain wear comes usually at link side bars. This is best overcome by making a template of 1¼-in. pipe, welding two attachment links at exact sprocket spacing and welding a squaring guide at the ends. This

facilitates uniform drilling of replacement flights and is also used to uniformly space all sprockets in a basin, thus simplifying a difficult alignment job, and minimizing abusive wear.

The use of spring steel in flat bar form for flat wearing services will increase life greatly. Common applications are return rails on grit channels, chain guides on mechanical bar screens, sludge flight wearing shoes (quickly tack welded on top of old shoe), etc.

Piping

In piping work, one of the most overlooked tools is the flange jack for separating flanged joints. Ring gaskets are easier to insert than full face gaskets. When sulfur compound joints fail in bell and spigot pipes, the use of bell joint clamps is a far quicker repair than repouring with lead. Plastic pipe 2 in. and smaller in diameter is a good replacement for water lines in particularly corrosive locations but the necessity for electrical grounding should not be overlooked. Properly chosen plastic pipe is suitable for smaller digester gas lines as well. Cast iron sludge lines should include long radius bends, sweep fittings, and frequent cleanout tees. A sketch of each underground valve showing pinpoint location is invaluable and should include data as to manufacturer, model, year, turns, and direction to open, etc. A small but important recommendation is to use a soft composition disc in check valves for air or vacuum service.

Electrical

Electrical maintenance cannot be entirely separated from mechanical. Type TW wire in conduit is generally best at sewage installations. All electrical wall outlets, extension cords, and cords on portable electric tools should be converted to the new three-wire grounding type. This is an important safety measure. Annually all connections should be tightened in panelboards, starters, etc. "Little arcs into big arcs grow." Motor burn-outs rarely are the fault of the motor but most commonly are due to failures of the overload protection built into the motor starter. Considerable testing indicates that solder ratchet (melting alloy) type overload relays are far superior to bi-metallic type and remain in trip calibration (1). Replacement overload relays may be readily mounted in or adjacent to existing motor starters.

Not a single motor burn-out has occurred in this organization since the initiation of the planned maintenance program three years ago, although over 130 motors of 5 to 175 horsepower are in operation. Accordingly, all pump and motor insurance has been confidently cancelled. It should be pointed out that operating policy should never permit more than one reset of overload trips until the responsible overload is cleared.

Summary Statement

Effective maintenance is tough, thankless, challenging, dirty, sometimes fun, and never ending, but never dull.

Reference

1. Thayer, R. C., and Smith, J. E., "Relay Test for Motor Protection at Sewage Pumping Stations." *Water and Sewage Works*, **103**, 6, 265 (1956).

RADIUM—LOST AND FOUND

By Ralph O. Wollan

Instructor, School of Public Health, and Health Physicist, University Health Service, University of Minnesota, Minneapolis, Minn.

On November 4, 1955, the Division of Environmental Health of the University Health Service received a call from the University Hospitals reporting the loss of a 25-mg radium capsule from one of the patient treatment wards.

Radium is a naturally occurring radioactive element. It emits a very powerful and, consequently, a potentially damaging type of radiation. The inherent danger from exposure to this radiation, however, is based on several contributing factors: (a) the quantity of radium in the capsule, (b) the length of time one spends in the field of radiation, and (c) one's proximity to the source of radiation. The amount of earth or water or other material, under which the capsule might be located, also determines the extent of radiation to which one will be exposed. Any material between the person and the radium, depending on the quantity and density of the material, tends to reduce the radiation level.

Encapsulated radium presents a radiation problem as described above. However, if the radium salt should escape through a rupture in the capsule, a problem of much greater significance may result. The radium can then contaminate the water, air, sewage, etc. and present an even greater hazard to health through ingestion and inhalation of radium-contaminated material, as well as through external exposure.

Action Taken

Immediately after being notified of the loss of the radium, the health physicist checked with all personnel, who were questioned on the radium treatment station in an effort to determine the possible location of the lost capsule. Radiation surveys were made on the ward and vicinity. All waste disposal containers, soiled linen containers, and other suspected equipment and furnishings in the hospital area were checked with a monitor. Two men with Geiger survey meters were dispatched to the hospital laundry to check on the possibility of the radium having left the hospital with soiled linen. Further information from the nursing staff led to the belief that the capsule may have fallen into a bedpan and subsequently dumped in the bedpan hopper, which would have carried it into the sewer.

From plans of the university sewerage system it was estimated that the capsule might have been temporarily held in the stilling basin at the bottom of the drop manhole in the interceptor system beneath the hospital.

The stilling basin for the drop manhole, into which the hospital sewage emptied, is located 80 ft underground. The only way to reach this location was to walk about a quarter of a mile through the interceptor sewer. The only access to the interceptors was through underground heating tunnels which lead to the entrance of the interceptor.

Radiation detection equipment was used to check the stilling basin. Each of the several members of the search team carried a radiation detection instrument having variable degrees of sensitivity. The difficulty of orienting oneself in the interceptor system resulted in extending the search to several similar stilling basins in the general vicinity. The radiation from the radium was finally detected with a Geiger counter in the hospital stilling basin, as was suspected.

Removal of the radiation source from the stilling basin, however, posed a problem considerably more difficult than that of locating it with a Geiger counter. It was first decided to dredge for the capsule by lowering a dredging clam into the manhole and down into the stilling basin.

Dredging

The manhole opening above the stilling basin was in a sidewalk in front of the hospital entrance. A string with a float attached was lowered down the manhole. The float by-passed the stilling basin and floated out into the interceptor sewer where it was recovered by one of the group waiting 80 ft below in the interceptor. A communication line was attached to the string to provide phone service from above ground to the crew below. The phone service proved invaluable in many ways during the dredging operation. It would also have provided the only means of communication, had either those above the ground or those below obtained the capsule. A small dredging clam was then lowered into the stilling basin and used repeatedly in an effort to bring the radium capsule to the surface. A wire screen was held in the sewage stream in the interceptor to catch the capsule if it should be disturbed by the clam and overflow with the sewage into the main stream. Radiation survey instruments were on hand at all times to check the contents of the dredging clam as well as the wire screens in the interceptor.

This method failed to reclaim the radiation source; therefore, further measures were necessary.

Flushing

In the second attempt, fire hoses were connected to a quick-opening valve located at the hydrant. The other end of the hose was lowered into the manhole. Intermittent surges of water were applied to the stilling basin in the hope of flushing the radium capsule, which was contained in a small rubber stopper, into the interceptor. It would then be captured by screens in the main sewage stream. The second attempt also failed to recover the capsule.

The following day a radiation check of the stilling basin revealed that the capsule was no longer at this location. It was assumed that a surge of sewage must have flushed it free and out into the main stream. Radiation surveys were made through the main interceptor as far as was possible in the hope that the capsule might have been temporarily held up. It was then assumed that the capsule passed through the Minneapolis and St. Paul sewer system to the treatment plant at Pigs Eye Island in St. Paul. At this time the State Health Department and the Minneapolis-St. Paul Sanitary District were notified.

Treatment Plant Survey

A complete radiation detection survey was made of the sewage treatment plant. Trucks carrying grit and screenings were checked to make sure that the capsule had not become lodged in the truck box. The truck route to the grit pile was surveyed as well as all other areas where the capsule might possibly be located.

While surveying one of the sludge incinerators which was down for repair, radiation levels of 4 to 5 times background were encountered in the incinerator openings. With the thought in mind that the capsule could have ruptured under the furnace heat, a more intensive survey was made of the incinerator and surrounding areas. It was found that radiation levels in this area in excess of background were due to the mass effect of thorium in the brick lining used in the incinerator.

Although the early efforts to locate the radium capsule failed, repeated surveys were made of all areas of the sewage treatment plant. Finally, on August 28, 1956, the radiation from

the radium capsule was detected using a portable scintillation detector. It had either been delayed in transit of escaped earlier detection and had been dumped with tons of screenings and grit along the banks of the Mississippi River at the sewage treatment plant.

Ten months after it was lost, and 15 miles from the original site of the loss, the radium capsule was recovered intact.

TIPS AND QUIPS

Sewage Treatment Growth

During the five years following the establishment of the Ohio water pollution law in 1951 and its effective date of September 1952, the sewage treatment capacity of municipal plants has virtually doubled. At the beginning of the period the total design capacity of all existing municipal sewage treatment plants was 575 million gpd, while at the end of the period the total capacity in operation or under construction reached 1.117 billion gpd. Approximately 25 per cent of these gains represents new treatment facilities in 31 cities and 54 villages, whereas the remaining 75 per cent was in expansion of outgrown sewage plants in 37 cities and 39 villages. These construction activities are expected to represent a cost of $250 million to state municipalities.

Sludge Pump Maintenance

For those who have found that the traditional ice pick is no longer a satisfactory tool for lifting the new hard ball checks out of piston sludge pumps, there comes a tip from the Walla Walla, Wash., sewage treatment plant. A special set of forceps was devised to do this job. The forceps have handles about 14 in. long and the clamping end just fits into the chamber. As a result there are no more check balls dropped into "loaded" chambers and no damage to the ball itself. For more detailed information contact Superintendent C. S. Zickefoose.

Industrial Waste Handling by Municipality

An industrial waste treatment system in Yakima, Wash., different from many in existence, may indicate the trend toward more municipal handling of industrial wastes. The city of Yakima is building a $400,000 spray irrigation system to handle canning waste, commencing with the 1958 season.

The treatment will be separate from the present municipal sewage treatment plant, but located at the plant site. The facilities consist of five miles of 24-in. sewer line, a pump station with two 100-hp electric pumps to deliver the canning waste through distribution lines and sprinkler heads at 90 psi. The spray area is 70 acres.

While there are many factors affecting a decision as to the means of treating industrial waste, where economics permit, municipal handling of the industrial waste, either in a combined treatment or in a separate system, has many advantages to both groups.

Statistics

Here are some statistics about the world's scientists which may be surprising to some:

88 per cent are married; most have children.
70 per cent are active in sports.
37 per cent engage in civic activities.
33 per cent do P.T.A. work.
75 per cent are affiliated with churches.

More About Russian Translations

It was earlier reported (THIS JOURNAL, **30**, 4, 554; Apr. 1958) that the American Society of Mechanical Engineers would translate into English one of the leading Russian journals. Now it is learned that there will be a paper available containing a concise vocabulary of Russian technical terms and useful expressions, together with an explanation of, and pronunciation guide for, the Russian alphabet. The purpose of this paper is to enable engineers to recognize enough words and phrases to discover whether a Soviet technical article is worth translating.

This paper, "Russian Vocabulary for Heat Transfer Literature," is authored by Mrs. F. F. Buckland of the General Electric Company, and is available for a nominal charge from ASME Order Department, 29 West 39th St., New York 18, N. Y., under the number 58-HT-9.

Utilization

It is a well-known fact that the solution to one problem often brings about others. This was demonstrated at Orlando, Fla., where experimental work was being carried on to recover plant food from sewage. To do this, water hyacinths were planted in the secondary clarifiers at the sewage treatment plant. When the nutrients in the sewage proved to be to the hyacinths' liking and the growth became so prolific that sedimentation efficiency was lowered, it was necessary to remove the plants. Hand removal became too costly, and as a result, Robert E. Simon, plant superintendent, found that a 4-in. Model C Wemco pump accomplished the job satisfactorily.

When you hire people who are smarter than you are you prove you are smarter than they are.

R. H. Grant

Slide Rule

An inexpensive, circular hard paper slide rule recently announced and shown in Figure 2 may be of interest to operators and others. Multiplication, division, and proportioning can be accomplished rapidly with this pocket-size calculator. Complete details are available from General Industrial Company, 5738 Elston Ave., Chicago 30, Ill.

FIGURE 2.—Circular, pocket-size slide rule.

Lagoon Waterproofing

While plastic sealing of soil is no longer new, it can be an important consideration in a situation where soil infiltration is a problem. One such method to line a pond or lagoon is with vinyl sheeting. Tests have shown that such a liner stopped a 3-in. per day loss. Vinyl sheeting is strong, durable, and mildew resistant. For field fabrication, the vinyl sheeting is heat sealed to form a tarpaulin. The large sheet is then unrolled onto the bottom and sides of the lagoon. The plastic is easily patched and is said to withstand winters without splitting or cracking.

Cost and other information can be obtained from the Bakelite Company, Division of Union Carbide Corp., 30 East 42nd St., New York, N. Y.

Federation Affairs

THIRTY-FIRST ANNUAL MEETING PREVIEW

Sheraton-Cadillac Hotel, Detroit, Michigan; October 6–9, 1958

★

HOST ASSOCIATION—MICHIGAN SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

★

THE OFFICIAL PROGRAM

SUNDAY, OCTOBER 5

Afternoon

Early Registration—Fourth Floor Lobby

MONDAY, OCTOBER 6

Morning

Registration—Fourth Floor Lobby
Inspection of Exhibits—Fourth Floor
Thirty-First Annual Meeting Called to Order—Grand Ballroom
President Kenneth S. Watson
Invocation—Dr. Robert M. Frehse
Welcome to Detroit—Mayor Lewis C. Miriani
Reports of Federation Officers
International Joint Commission Activities
Hon. Douglas S. McKay, Chairman, U. S. Section, International Joint Commission, Washington, D. C.
Ontario Moves Ahead on Water Resources Programming
Dr. A. E. Berry, General Manager, Ontario Water Resources Commission, Toronto, Ont., Canada

Afternoon

Effect of Impoundment on Dissolved Oxygen Resources in Streams
F. W. Kittrell, In Charge, Stream Sanitation Studies, Water Supply and Water Pollution Control Program, USPHS, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio
Discussion: S. Leary Jones, Director, Stream Pollution Control, Tennessee Department of Public Health, Nashville, Tenn.
Discussion: Robert S. Ingols, Head, Department of Public Health, Georgia Institute of Technology, Atlanta, Ga.

Comments on ASCE-FSIWA Manual of Sewage Treatment Plant Design
Daniel A. Okun, Head, Department of Sanitary Engineering, University of North Carolina, Chapel Hill, N. C.

Design and Operation of Activated Sludge Plant in Edmonton, Alberta
Norman McDonald, President, Gore and Storrie, Consulting Engineers, Toronto, Ont., Canada

Compulsory Licensing of Operators
Donald M. Pierce, Chief, Section of Sewerage and Sewage Treatment, Division of Engineering, Michigan Department of Health, Lansing, Mich.

Voluntary Licensing of Operators
Don W. Jones, Superintendent, Water and Sewers, North Miami, Fla.

Sewage Treatment Needs of the United States
Gordon E. McCallum, Chief, and John R. Thoman, Senior Sanitary Engineer, Water Supply and Water Pollution Control Program, USPHS, Washington, D. C.

Evening

Family Night Entertainment—Grand Ballroom

TUESDAY, OCTOBER 7

Morning—Concurrent Sessions

SYMPOSIUM ON COST REDUCTION

Reduction of Sewage Treatment Costs by Use of Advanced Practice in Activated Sludge and Sludge Digestion
Richard H. Gould, Consulting Engineer, Douglaston, N. Y.

How To Reduce Sewage Plant Construction Costs
A. W. Sawyer, Partner, Hazen and Sawyer, Consulting Engineers, New York, N. Y.

How to Reduce Costs of Sewage Treatment Plant Operation
E. J. Beatty, Engineer-Manager, Champaign-Urbana Sanitary District, Urbana, Ill.

How Far Can We Go?
Walter W. Saxton, Associate Engineer, Washington State Pollution Control Commission, Olympia, Wash.

SYNTHETIC DETERGENT SESSION

Removal of ABS by Sewage Treatment Processes
P. H. McGauhey and S. A. Klein, Sanitary Engineering Research Laboratory, University of California, Richmond, Calif.

Evaluation of Frothing in Sewage Treatment
G. A. Rohlich, L. B. Polkowski, and J. R. Simpson, College of Engineering, Hydraulic and Sanitary Laboratory, University of Wisconsin, Madison, Wis.

Biochemistry of ABS Metabolism
Ross E. McKinney and James M. Symons, Department of Civil and Sanitary Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

Studies on the Occurrence and Degradation of Condensed Phosphate in Surface Waters

R. S. Engelbrecht and James J. Morgan, Department of Civil Engineering, University of Illinois, Urbana, Ill.

Absorption of ABS by Inorganic Fines

Charles E. Renn and Mary F. Barada, Department of Sanitary Engineering, Johns Hopkins University, Baltimore, Md.

Noon

FEDERATION LUNCHEON

The Enrico Fermi Atomic Power Plant

Robert W. Hartwell, General Manager, Power Reactor Development Company, Detroit, Mich.

Afternoon

CONCURRENT INSPECTION TRIPS

Detroit Sewage Treatment Works

Ford Motor Company Industrial Wastes Treatment Works Trip to: (a) steel rolling mill waste treatment at Rouge Plant, Dearborn, Mich.; (b) combined water supply and electroplating waste treatment at Parts and Equipment Manufacturing Division, Monroe, Mich.; (c) automotive exhibits at Ford Rotunda, Dearborn, Mich.

WEDNESDAY, OCTOBER 8

Breakfast

Laboratory Scientists' Breakfast—Toxicity Determinations

Gail P. Edwards, Leader, Professor of Sanitary Chemistry, New York University, New York, N. Y.

Morning—Concurrent Sessions

Motion Picture, "Engineering Your Health," A USPHS Film

SEWER MAINTENANCE PANEL

Sydney A. Preen, Leader, Superintendent, Sewer Maintenance, Long Beach, Calif.

Grant Olewiler, Superintendent, Sanitary Drainage, Lower Merion Township, Ardmore, Pa.

M. B. Nixon, Engineer, Sewage Treatment, Atlanta, Ga.

John Klamm, Superintendent, Sewer Maintenance, Kansas City, Mo.

PLANT MAINTENANCE PANEL

John C. Sager, Leader, Engineer of Maintenance and Design, Minneapolis-St. Paul Sanitary District, St. Paul, Minn.

Fred H. Burley, Superintendent, Sewage Treatment Works, Detroit, Mich.

Clifford Irving, Superintendent, Bureau of Sewage Treatment, Schenectady, N. Y.

Arthur D. Caster, Principal Sewage Disposal Engineer, City of Cincinnati, Ohio

SYMPOSIUM ON INDUSTRY-MUNICIPALITY COOPERATION

Unusual Industrial and Municipal Cooperation for Joint Treatment of Wastes—The American Cyanamid Company and the Somerset-Raritan Valley Sewage Authority

Part I—Industry's Approach and Position

S. T. Powell, Consulting Chemical Engineer, Baltimore, Md., and James C. Lamb, III, Sanitary Engineer, American Cyanamid Company, Bound Brook, N. J.

Part II—Municipality Approach and Position

Roy H. Ritter, Partner, Whitman and Requardt, Consulting Engineers, Baltimore, Md.

The Amarillo Sewage Plant Effluent as a Source of Water Supply for The Texas Company

Clarence Scherer, Superintendent, Sewage Treatment and Water Reclamation, Amarillo, Tex., and Dean Alexander, Engineer, The Texas Company, Amarillo, Tex.

Treatment of Metal Processing Wastes at General Electric's Conneaut, Ohio, Plant

O. W. Nyquist, Plant Engineer, and H. R. Carroll, Chemical Engineer, General Electric Company, Conneaut, Ohio.

Tidewater's Delaware Refinery Waste Control and Treatment

A. W. Lewis, Director, Refinery Technology, Tidewater Oil Company, Delaware City, Del., and A. J. Kaplovsky, Supervising Engineer, Delaware Water Pollution Commission, Dover, Del.

Noon

INDUSTRIAL WASTES LUNCHEON

Water Resources and Industrial Management

W. H. Schuette, General Manager, Midland Division, Dow Chemical Company, Midland, Mich.

Afternoon—Concurrent Sessions

INDUSTRIAL WASTES SESSION

Treatment of Industrial Wastes from Automotive Plants

David Milne, Supervisor, Materials and Processes, General Motors Production Engineering Section, Detroit, Mich., A. R. Balden, Staff Engineer, Chemical Engineering Department, Chrysler Motor Corporation, Detroit, Mich., and F. J. Kallin, Chief Civil Engineer, Engineering and Planning Department, Ford Motor Company, Dearborn, Mich.

Composting Industrial Waste Sludge

A. J. Gabbaccia, Lederle Laboratories Division, American Cyanamid Company, Pearl River, N. Y.

General Electric's Approach for Waste Control in the Private Atomic Power Industry

James M. Smith, Jr., Radiological Engineer, General Electric Company, San Jose, Calif.

RESEARCH SYMPOSIUM

Metabolic Energy Balances in a Total Oxidation Activated Sludge System

R. Rupert Kountz, Professor of Sanitary Engineering, and Charles Forney, Jr., Instructor in Civil Engineering, The Pennsylvania State University, University Park, Pa.

Investigation of Fundamental Principles of Trickling Filters
Don E. Bloodgood, Professor of Sanitary Engineering, G. H. Teletzke, Associate Professor of Sanitary Engineering, and F. G. Pohland, Graduate Student, Purdue University, Lafayette, Ind.

The Anaerobic Process as Applied to Sewage and Industrial Wastes
George J. Schroepfer, Professor of Sanitary Engineering, and N. R. Ziemke, Research Fellow, University of Minnesota, Minneapolis, Minn.

Determination of Toxic Organic Substances in the Aquatic Environment. I. Organo-Phosphorus Insecticides
Charles M. Weiss, Associate Professor of Sanitary Science, University of North Carolina, Chapel Hill, N. C.

Evening

ANNUAL FEDERATION AWARDS DINNER AND DANCE

THURSDAY, OCTOBER 9

Morning—Concurrent Sessions

OPERATORS' FORUM

Control of Digester Scum, Gas Circulation, and Mechanical Mixing
Hugh A. Schreiber, Superintendent, Sewage Treatment Plant, Washington, D. C.

Grease and Skimmings Removal, Handling, and Disposal
Roger D. Lee, Sewage Treatment Division, Wichita, Kans.

Operators' Certification, Voluntary and Compulsory
Thomas T. Hay, Superintendent, Sewage Treatment, Racine, Wis.

INDUSTRIAL WASTES SYMPOSIUM—THE PETROCHEMICAL INDUSTRY

Basic Petrochemical Processes as Waste Sources
W. L. Ruggles, Phillips Petroleum Company, Bartlesville, Okla.

Secondary Petrochemical Processes as Waste Sources
E. R. Wright, Texas Division, The Dow Chemical Company, Freeport, Tex.

Alkaline Wastes
Alec McRae, Imperial Oil Company, Sarnia, Ont., Canada.

Condensates, Quenches, and Wash Waters
Harold Elkin, Sun Oil Company, Philadelphia, Pa.

Tars, Spent Catalysts, and Complexes
Jack T. Garrett, Monsanto Chemical Company, St. Louis, Mo.

Summation—Need for More Definitive Characterization
M. B. Ettinger, USPHS, Cincinnati, Ohio

TECHNICAL PROGRAM COMMENTS

This year's meeting with ten sessions offers the most expansive technical program ever included in a Federation meeting. The Program Committee, under the Chairmanship of George E. Symons, has labored diligently and made careful selections of program material to represent the current state of knowledge and developments in the many aspects of the sewage and industrial wastes field.

Insofar as possible, concurrent sessions have been arranged so that the choice of paper or session will inconvenience those attending the meeting to a minimum. The Operator's Forum and the Industrial Wastes Symposium scheduled for Thursday morning are timed for discussion from the floor. Those attending these sessions, particularly, are urged to come prepared to contribute by offering questions or discussion in line with the subjects included.

Again the Research Forum has been arranged and half-session panels, dealing with sewer maintenance in one and plant maintenance in another, are expected to give full coverage to these subjects.

The Laboratory Scientists' Breakfast is scheduled for the third consecutive year. With the state of preparation of the 11th Edition of "Standard Methods," this session is certain to be even more popular than before.

Several sessions are scheduled to include papers of industrial wastes interest only, and a strong array of papers will be included for those with trade wastes as a principal interest.

The inspection trips Tuesday afternoon include a visit to the Detroit Sewage Treatment Plant. While such a visit was made during the 1948 meeting, it will be of interest to see this plant with enlargements made necessary by growth of the area served. At the same time, an alternate trip is available for those with a primary interest in industrial wastes. Since the automotive and related industries are of special interest in Detroit, waste treatment in this area will be featured.

Technical sessions will be held in the Grand Ballroom, Fourth Floor of the Sheraton-Cadillac. Concurrent sessions will use the English Room on the Mezzanine Floor.

OTHER FUNCTIONS

The Monday Evening Family Night entertainment will feature assembly entertainment in the Grand Ballroom. A variety show has been arranged by the Detroit Entertainment Committee. A principal feature will be dancing and singing by 28 members of the famous Chrysler Chorus and Glee Club. Other program items will include interesting and fast-moving acts.

The Federation Luncheon is set for Tuesday Noon with Robert W. Hartwell, General Manager, Power Reactor Development Company, Detroit, Mich., speaking on "The Enrico Fermi Atomic Power Plant."

Tuesday Evening includes no generally planned convention event. The Local Host Committee will be pleased to help those attending to plan a program to suit individual desires.

A dinner meeting of the Loyal Order of the Boar is scheduled for Tuesday at 6:00 PM. Arrangements are in charge of W. A. Hardenbergh and J. J. Gilbert. Members and guests may purchase tickets at the Local Host Desk.

On Wednesday morning, the Conference of State Sanitary Engineers will have a breakfast meeting which will precede a meeting of its National Water Policy Committee.

A new program feature, the Industrial Wastes Luncheon, is set for Wednesday. The speaker will be W. H. Schuette, General Manager, Midland Division of Dow Chemical Company. His subject is "Water Resources and Industrial Management."

The general Federation Awards Banquet and Dance on Wednesday evening provides the social peak of the Federation year. Instead of formal speaking there will be the annual presentation of Federation awards, honors, and new officers, followed by dancing. Dress is optional.

LADIES' ENTERTAINMENT

The ladies' group of the Local Arrangements Committee has planned a most interesting visit to Detroit for the ladies attending the Federation meeting. The events given in the following paragraphs are in addition to the Monday night entertainment and the Wednesday Banquet and Dance already listed.

On Monday morning, from 9:00 AM to 11:00 AM, the ladies are invited to gather in the Ladies' Headquarters, the Pan-American Room on the fifth floor of the Sheraton-Cadillac, for breakfast snack and coffee. This event, which will provide a setting for renewing acquaintances and making new ones, is sponsored by the Host Association, the Michigan Sewage and Industrial Wastes Association. Monday afternoon will be available for card playing, visiting, and shopping in the retail district which is convenient to the hotel.

On Tuesday, the ladies will go by bus to Ford's Greenfield Village at Dearborn. A group luncheon will be provided at Lovett Hall and afterward the ladies may spend the afternoon touring the village or visiting the Henry Ford Museum.

On Wednesday morning the ladies will make a scenic bus tour of the city including Detroit's waterfront and Belle Isle, with lunch at the Veterans Memorial Building. This schedule will make it possible for ladies to return to the hotel by early or mid-afternoon.

Tickets for the tours and luncheons are included in the general ladies' registration fee.

TECHNICAL INSPECTIONS

Tuesday afternoon has been set aside for inspection trips. Two trips are offered: the trip to the Detroit Sewage Treatment Plant and the Ford Motor Company trip. The latter includes: (a) steel rolling mill waste treatment at Rouge Plant, Dearborn, Mich.; (b) combined water supply and electroplating waste treatment at Parts and Equipment Manufacturing Division, Monroe, Mich., and (c) automotive exhibits at Ford Rotunda, Dearborn, Mich.

Bus transportation for these inspection trips has been arranged at a nominal fee and trip tickets will be available at the Registration Desk. Early purchase of these tickets will help avoid disappointment.

The Local Host Committee has prepared additional inspection trip itineraries for Thursday afternoon which will not conflict with any technical sessions. Full information will be available at the Local Host Committee Desk.

EXHIBITS

Displays of the latest in equipment and supplies will be offered by members of the Water and Sewage Works Manufacturers Association on the fourth floor of the Sheraton-Cadillac Hotel. All available space has been allocated. These exhibits provide a setting for the introduction and explanation of new methods and equipment. A detailed view of the exhibits is necessary to full participation in the meeting.

The following companies have engaged exhibit space:

Airkem, Inc.
American City Magazine
Armco Drainage & Metal Products, Inc.
B-I-F Industries, Inc.
Burgess-Manning Co., Penn Instruments Division
Carter Co., Ralph B.
Chain Belt Co.
Chicago Pump Co.
Combustion Engineering, Inc., Raymond Division
DeZurik Corp.
Dorr-Oliver, Inc.
Eimco Corp.
Engineering News-Record
Fischer & Porter Co.
Foxboro Co.
Hardinge Co., Inc.
Homestead Valve Manufacturing Co.
Inertol Co., Inc.
Infilco Inc.
Jeffrey Manufacturing Co.
Johns-Manville
Keasbey & Mattison Co.
Komline-Sanderson Engineering Corp.
Lakeside Engineering Corp.
Link-Belt Co.
Lock Joint Pipe Co.
Nichols Engineering & Research Corp.
Pacific Flush Tank Co.
Price Brothers Co.
Public Works Publications
Robinson Clay Products Co.
Roots-Connersville Blower Division, Dresser Industries, Inc.
Simplex Valve and Meter Co.
Smith-Blair, Inc.
Smith & Loveless, Inc.
Stuart Corp.
Technion Controls, Inc.
Vapor Recovery Systems Co.
Walker Process Equipment, Inc.
Wallace & Tiernan Inc.
Wastes Engineering
Water & Sewage Works
Western Machinery Co.
Worthington Corp.
Yeomans Brothers Co.

REGISTRATION INFORMATION

Detroit is on Eastern Standard Time throughout the year

Registration facilities will be located on the fourth floor lobby of the Sheraton-Cadillac Hotel from Sunday afternoon, October 5, through Wednesday, October 8. Convention attendants are urged to take advantage of the pre-registration plan which was described in full by a flyer to the whole Federation membership about September 1. This will make it possible to pick up tickets and badges at the Registration Desk on arrival. All attending are urged to register promptly to avoid the Monday morning rush. On Sunday, the Registration Desk will be open from 1:00 to 6:00 PM and on Monday, Tuesday, and Wednesday, the Registration Desk will be open from 8:30 AM to 5:00 PM.

The men's registration fee of $13 will include admission to the technical sessions, the Family Night Entertainment on Monday, and the Annual Awards Dinner and Dance on Wednesday evening. Separately, the registration fee (required for admission badges to the technical sessions) is $7 and the Wednesday Dinner and Dance combination is $6.

Ladies' registration at $13 includes the Monday morning snack and coffee (provided by the Michigan Association), the Monday evening entertainment, the Tuesday trip to Greenfield Village with luncheon, the Wednesday morning scenic tour of Detroit with luncheon, and the Wednesday evening Dinner and Dance. Separately, the tickets are $7 for the special ladies' events and $6 for the Annual Awards Dinner and Dance.

Individual tickets will be sold for the Federation Luncheon on Tuesday, the Tuesday afternoon Inspection Trips, the Laboratory Scientists' Breakfast on Wednesday, and the Industrial Wastes Luncheon on Wednesday.

PREREGISTRATION INFORMATION

Since the preregistration plan offered with the 1957 meeting met with such general acceptance, a similar plan is offered this year. Advance registration will save time, as badges and tickets will be ready for you to pick up upon arrival at the registration area during registration hours. Checks may be dated October 9, 1958, if this should be a convenience.

Should your plans change, a full refund will be made if your badge and tickets are not picked up at the Detroit meeting. Tickets must be picked up a half business day prior to the Tuesday Luncheon, the Wednesday Luncheon, or the Wednesday Banquet, as the Federation makes guarantees for these functions. If the tickets are claimed later, there can be no assurance of a place at these functions. Should a part of the remittance go unused for this reason, it will be refunded at the time your registration is claimed.

To assure proper handling of your preregistration, your completed registration card must be **received** in the Federation office by Friday, September 26, so that you may be assured of processing in time for the meeting.

A postcard or letter request to the Federation of Sewage and Industrial Wastes Associations, 4435 Wisconsin Avenue, Washington 16, D. C. will bring a registration card and complete information by return mail.

HOTEL ARRANGEMENTS

Requests for room reservations should be made as early as possible to the Sheraton-Cadillac Hotel, Detroit 31, Mich., indicating your interest in this Meeting.

LOCAL ARRANGEMENTS COMMITTEE

The Local Arrangements Committee with Clyde L. Palmer, Assistant City Engineer of Detroit, as General Chairman, and Samuel D. Porter as General Vice-Chairman is made up of the following who are chairmen of the respective subcommittees:

Finance Committee: George E. Hubbell, Chairman; Robert J. Peterson and Stuart H. Bogue.

Hotel Arrangements Committee: J. E. Cooper, Chairman; Cletus Courchaine, Huntley Delano, Ronald Swets, and J. A. Borchardt.

Registration Committee: Donald M. Pierce, Chairman; Wallace J. Benzie, Clair Johnson, Herbert Zinsmeister, M. S. Richmond, and Robert J. Peterson.

Entertainment Committee: Michael Groen, Chairman; Clark Hathaway, William Assenmacher, and Floyd Vermette.

Inspection Trip Committee: Fred H. Burley, Chairman; Loring F. Oeming, Virgil Anderson, John Engle, and Harold Leonard.

Local Host Committee: Milton P. Adams, Chairman; Mrs. Milton P. Adams, Mr. & Mrs. Frank Kallin, Mr. & Mrs. Harry Thomas, Clark Hathaway, Mr. & Mrs. Robert Zumstein, Albert Kunze, Mr. & Mrs. Gerald Remus, Mr. & Mrs. Robert J. Peterson, and Mr. & Mrs. Samuel D. Porter.

Ladies' Entertainment Committee: Mrs. Harry Thomas, Chairman; Mrs. J. E. Cooper, Mrs. Michael Groen, Mrs. George Hubbell, Mrs. Virgil Anderson, Mrs. Frederick Burley, Mrs. George Wyllie, and Mrs. Donald M. Pierce.

Publicity Committee: Carl Walker, Chairman.

Reviews and Abstracts*

Treatment of Strong Iron-and CO_2-Producing Lignite Mine Wastes. By W. Rummel. *Wasserwirtsch. Tech.*, 7, 5, 183 (May 1957).

The treatment of lignite mining wastes from Lausitz proceeds in two steps: primary and secondary. Theoretical considerations and practical examples illustrate the conditions of treatment. In primary treatment it is important to note the economy in lime and sludge storage space against that provided in former methods of treatment. In spite of the high content of free dissolved carbon dioxide, only a slight increase in carbonate hardness is shown. Secondary treatment is provided in accordance with the desired requirements for purity of treated waters and may involve boiler water treatment, rapid sand filtration, disinfection, etc.

Conrad P. Straub

Effect of Various Methods of Sewage Treatment on the Destruction of Nematode Ova. By W. Dożańska and I. Iwańczuk. *Gaz. Woda i Tech. San.*, 31, 6, 214 (June 1957).

Factors affecting the viability of parasite eggs in external media (sewage, sediments, soils, etc.) are: high temperatures, desiccation (sun's rays), or prolonged contact of the eggs under anaerobic conditions. Best results for destroying the eggs in sewage and sewage sediments are obtained with sedimentation of the eggs in settling basins, irrigation fields and filtration, sand filtration, chemical coagulation, and prolonged anaerobic digestion. Before digestion, it is suggested that the sludge be heated to a temperature of 55°C for 2 hr. Chemical substances used for disinfection (for example, chlorine and its compounds) are ineffective for the destruction of nematode eggs. Agricultural utilization of sewage or sludge should be carried out under great care and direction, preferably after destruction of the ova in order to protect humans and animals from disease. The authors suggest the need for further studies to determine the viability of the ova under Polish climatic conditions.

Conrad P. Straub

Quantitative Determination of Volatile Acids by Paper Chromatography for Application to Sewage Sludge Digestion. By R. M. Manganelli and F. R. Brofazi. *Anal. Chem.*, **29**, 1441 (1957).

A new paper chromatographic method for separation of volatile C_2 to C_6 fatty acids is applied to sewage sludge digestion studies. The acids are separated as ethylamine salts in a butanol-water ethylamine system. Color of the acid spots is developed with chlorophenol red. Concentration of the acid present is proportional to the area of the spot.

R. S. Ingols

Behavior of Cyanates in Polluted Water. By J. D. Resnick, W. A. Moore and M. B. Ettinger. *Ind. and Eng. Chem.*, **50**, 71 (1958).

Cyanates under anaerobic conditions are reduced to a mixture of ammonia and formic acid, not cyanide. Under aerobic conditions, the cyanates were stable for the 10 days of observation at pH 7 and 20°C. It is suggested that there should be a study of a possible reevaluation of the requirements for cyanide treatment in waste streams.

R. S. Ingols

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Federation of Sewage and Industrial Wastes Assns., 4435 Wisconsin Ave., N. W., Washington 16, D. C.

The Disposal of Sewage Sludge. By W. F. Brown. *Proc. Inst. Civil Eng. (Brit.)*, **8**, 409 (1957).

The primary considerations in choosing a method of sludge treatment are those of public health and the avoidance of a public nuisance. Anaerobic digestion makes sewage sludge less objectionable, easier to dewater, and safer, besides providing a high calorific fuel gas.

Economic factors and geographical location play a large part in determining the method of sludge treatment. Barging out to sea can only be practiced in coastal or estuarine towns; lagooning requires large areas of disused land close to the sewage works; land application is feasible only where arable land is close at hand and storage facilities are available.

In British practice sewage sludge is usually dried in open, under-drained beds, then stripped and dumped; covered beds and the use of mechanical strippers would improve this process.

The economic position of Britain demands sludge utilization as opposed to sludge disposal.

D. Jenkins

The Water Pollution Aspect of Refuse Disposal. By J. Longwell. *Proc. Inst. Civil Eng. (Brit.)*, **8**, 420 (1957).

A household refuse sample was shown to contain about 25 per cent vegetable and putrescible matter. Aqueous extracts of the refuse produced a liquor which corresponded to 4.5 lb permanganate value, 0.31 lb ammonia nitrogen, and 2.2 lb chlorides per ton of refuse, respectively. Further putrefaction would produce more extractable pollution.

Impurities are extracted from refuse when wet tipping is practiced. Anaerobic conditions are soon produced and any sulfate may be reduced to sulfide; mineral salts and bacterial counts also increase.

Direct access of this polluting effluent to an underground water may not cause anything more than local bacterial contamination, but may cause limited organic pollution. The effects of wet tipping at Egham in Great Britain and Krefeld in Germany are quoted.

Mineral salts were found to travel some distance before dilution effects were observed.

Experiments on recharging of ground water with a 10 per cent raw sewage (2.4×10^6 coliform organisms/100 ml) showed that no bacteria could be detected more than 100 ft from the recharge well.

Pilot-scale experiments on dry tipping of household refuse have been carried out at Bushey by the Ministry of Housing and Local Government. Bacterial pollution was found not to persist after filtration through gravel.

An effluent was produced by the percolation of rain water through a dry pit filled with refuse. The average percolate was 35 per cent of the rainfall per year. The BOD of the percolate fell from 7,000 to 20 ppm over a period of years. The results of these pilot-scale experiments must be confirmed in natural sites before their results are applied in practice.

D. Jenkins

BOOKS, REPORTS, PAMPHLETS

Water Quality and Flow Variations in the Ohio River, 1951–55. Ohio River Valley Water Sanitation Comm., 414 Walnut St., Cincinnati, Ohio. 112 pp. Price, $2.00 (1957).

A recording of continuous chemical and bacteriological analyses from a network of monitor stations on the Ohio River.

Water Pollution Research 1956. Dept. of Scientific and Industrial Research, Her Majesty's Stat. Off., London, England (1957).

The always interesting and informative report of the British Water Pollution Research Board. Available from British Information Services, 45 Rockefeller Plaza, New York 20, N. Y. Price, $0.77 postpaid.

The Industrial pH Handbook. By Thomas J. Kehoe, Beckman Instruments, Inc., Fullerton, Calif. 80 pp. Price, $2.00 (1957).

A review of industrial pH control systems, their principles, application, engineering, and equipment.

Underground Corrosion. By Melvin Romanoff, Natl. Bur. of Standards, Washington, D. C. Circular 579, 22 pp. Price, $3.00 (1957).

Book Reviews

Aspects of River Pollution. By Louis Klein. Academic Press, Inc., New York 3, N. Y. Price $14.50 (1957).

In this book the author, who is now Chief Chemist of the Marsey River Board (England), records his many observations and experiences in the field of surface water pollution. Because of his broad approach, it is interesting, useful, and valuable to anyone concerned with water pollution. The entire volume is generously footnoted to source material in which literature published in the United States is well represented.

Chapter headings are: Historical Introduction; Legal Aspects of River Pollution; Nature and Effects of Pollution; Causes of River Pollution; Uses of River Water; Biochemical and Physico-Chemical Aspects of River Pollution; Fish and River Pollution; Biological Aspects of River Pollution; Detection and Measurement of River Pollution; Significance and Interpretation of Chemical Tests; Physical Characteristics of Rivers; Abatement of Pollution. I. Sewage Disposal and Purification. II. Disposal and Treatment of Trade Wastes; Standards for Rivers, Sewage Effluents, and Trade Effluents; and Present and Future Status of River Pollution.

While the entire volume reflects the appealing technical philosophy of the author, the final chapter is a most fitting conclusion to such a meritorious work.

R. E. Fuhrman

Dangerous Properties of Industrial Materials. By N. Irving Sax. Reinhold Publishing Corporation, New York 22, N. Y. 1467 pp. Price $22.50 (1957).

This compendium of information will be useful to those concerned with the toxic properties of chemical compounds whether used in processes or occurring in wastes. About 225 pages are devoted to 9 sections with the following headings: Toxicology; Ventilation Control; Personnel Protection and Personal Hygiene; Atmospheric Pollution; Radiation Hazards; Industrial Fire Protection; Storage and Handling of Hazardous Materials; Reactor Safeguards; and Allergic Disease in Industry.

A major section of the book consisting of over 1,000 pages gives specific information on 8,500 materials. The information on each material includes: synonyms, description, formula, constants, toxic hazard rating, fire hazard, explosion hazard, personnel protection, personal hygiene, and storage and handling.

Shipping regulations applicable to the shipping of dangerous materials within the United States as prepared by the U. S. Interstate Commerce Commission, and made effective June 18, 1957, are given. There is also included a full index to synonyms of the materials mentioned in the book to assist the reader in conversion of common or technical names.

R. E. Fuhrman

Elements of Water Supply and Waste-Water Disposal. By Gordon M. Fair and John C. Geyer. John Wiley & Sons, Inc., New York, N. Y. 615 pp. Price $8.95 (1958).

In this book the authors have selected material from "Water Supply and Waste-Water Disposal," which they published in 1954. For a review of the previous volume, see This Journal, **26**, 12, 1515 (Dec. 1954).

The new book is specifically directed to the training of undergraduate students of civil and sanitary engineering. It emphasizes the scientific principles on which water supply and waste-water disposal are based. In addition to the description of physical systems in general, this book follows its predecessor in treating the two parts of the subject jointly rather than separately. This eliminates the need for duplicate description, discussion, and presentation of basically similar techniques. Should the user desire to follow the classic divisions of the subject, the applicable sections are listed in the preface as a guide.

A collection of 175 problems at the end of the book gives ample opportunity for application of the principles which the book presents in a most orderly fashion.

R. E. Fuhrman

GRAVER SYSTEMS SIMPLIFY TREATMENT OF COMPLICATED PLATING WASTES at MARTIN-ORLANDO

Building missiles is a complex job. Thousands of intricate parts must be machined to close tolerances and plated or coated with a wide variety of materials to resist corrosion and guarantee dependable performance during flight. Many are chrome plated, silver plated, anodized, phosphatized, pickled, passivated or processed in other ways. An unusually large number of acid and chemical wastes results, including nitric acid, hydrofluoric acid, sulfuric acid, caustic and cyanide. Handling these wastes is a complex problem in itself.

Martin-Orlando of Florida, builders of guided missiles, selected Graver to supply all units and auxiliary equipment for a treatment plant based on plans and specifications prepared by the Architect-Engineers. Graver, working with the consulting engineers, fabricated and installed a plant which handles this treatment problem simply and directly. Four integrated systems effectively treat all wastes in the spent baths and rinse. The plant is safe, efficient and simple to operate and maintain.

This installation is only one of the many modern plating waste treatment systems Graver has furnished for large and small manufacturers in every field. Graver supplies all types of equipment, from simple units to entire plants and makes available a complete service, including research and development, manufacturing and installation, when required. Whatever *your* waste treatment requirements, Graver has the modern designs, equipment and processes to do the job efficiently . . . economically. Every installation is tailored to specific needs.

GRAVER

Industrial Waste Treatment Dept. W-520
GRAVER WATER CONDITIONING CO.
Division of Union Tank Car Company
216 West 14th Street, New York 11, N. Y.

Architects & Engineers:
Connell, Pierce, Garland & Friedman
Miami, Florida

WRITE FOR INFORMATION AND LITERATURE!

Proceedings of Member Associations

MONTANA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 14th Annual Meeting of the Montana Sewage and Industrial Wastes Association was held on March 20–21, 1958, at the Florence Hotel in Missoula, Mont., in conjunction with the Montana Section, AWWA.

Papers of particular interest to sewage and industrial wastes personnel included the following:

"Sewage Lagoons," by Jerome Svore, USPHS, Portland, Ore.

"Design Construction and Maintenance of Sewers," by J. C. Seeger, Sanitary Engineer, Conservation Bureau, Portland Cement Assn., Chicago, Ill.

A highlight of the meeting was a symposium on pollution abatement with Claude W. Eyer, City Engineer, Glendive, Mont., presiding. Participating were: C. W. Brinck, Director, Division of Environmental Sanitation, Montana State Board of Health; John C. Spindler, Pollution Biologist, State Fish and Game Dept.; and John W. Hazen, Manager, Butte Water Co., Anaconda Co. Waste Disposal.

At the business meeting the following officers were elected for 1958–59:

Chairman: R. C. Fargo, Havre.
Vice-Chairman: E. R. Waldo, Billings.
Secretary-Treasurer: A. W. Clarkson, Helena.

A. W. Clarkson,
Secretary-Treasurer

(Continued on page 366a)

WEMCO the INCREDIBLE Torque-Flow Pump

pumps almost everything
(what will go in will come out)

secret: recessed impeller; continuous open passage
(with downtime virtually eliminated)

Western Machinery Company 650 Fifth St. San Francisco, California

PUT THE SQUEEZE ON INFILTRATION

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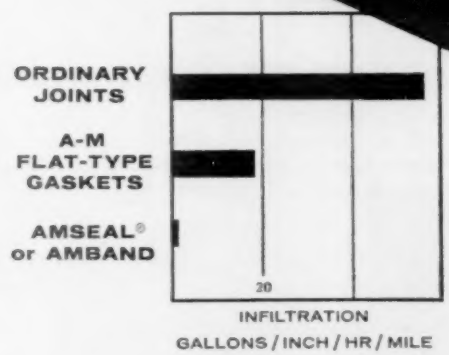
Rubber Gasketed Pipe



American-Marietta flat-type gaskets and longer length pipe reduce leakage and provide savings through faster installation with fewer joints.

For positive control of infiltration specify AMSEAL (Rubber and Steel Joints) or AMBAND (Fiberglass-Resin-Collar Joints).

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NEW YORK SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The Spring Meeting of the New York Sewage and Industrial Wastes Assn. was held at the Grossinger Hotel, Liberty, N. Y., May 26–27, 1958. A total of 187 members and guests, including 54 ladies, attended.

At the first technical session a film entitled, "We Have Come a Long Way," was shown by William L. Prinsen, Inc., of Rochester, N. Y. The film dealt with sewer cleaning techniques.

The following technical papers were presented:

"Determination of Suspended Solids in Sewage Using a Spectrophotometer," by D. F. Krawczyk and N. E. Gonglewski, Associate Chemist and Sanitary Chemist, respectively, of the Buffalo Sewer Authority.

"Lagoon Aeration of Wastes," by D. J. O'Conner and W. W. Eckenfelder, Jr., Associate Professors of Sanitary Engineering, Manhattan College. This was followed by a discussion by H. E. Orford of the Department of Sanitation, Rutgers University.

"Cleaning of Outfall Sewer at Coney Island Sewage Treatment Plant, New York City," by A. J. Scanlon, Chief of the Bureau of Sewage Disposal Operation, New York City Department of Public Works.

"Disposal of Radioactive Wastes at Mount Kisco, N. Y.," by R. M. McLaughlin, Director of Environmental Sanitation, Westchester County Health Department.

The second day's technical session was given over to a panel discussion on "Operating Problems of Industrial Waste Treatment Plants." Federation President, K. S. Watson of the General Electric Co., Schenectady,

(*Continued on page 368a*)

SNOW GATES

for

SEWAGE TREATMENT PLANTS

All types of cast iron gates manufactured in either square or circular opening in sizes up to and including 72 inches.

ALL SNOW GATES and Lifts are "Parkerized" for protection against rust and corrosion.

Over 40 years continuous service to the industry.

We will be pleased to quote on any type of water controlling equipment.

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Smith & Loveless FACTORY-BUILT LIFT STATIONS AND SEWAGE TREATMENT PLANTS

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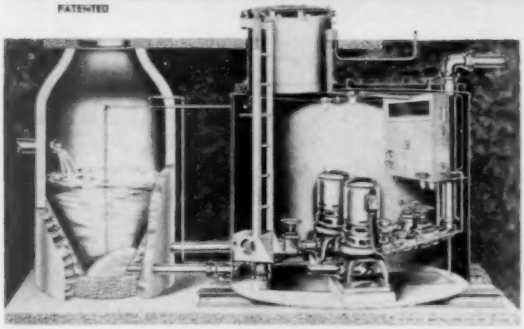

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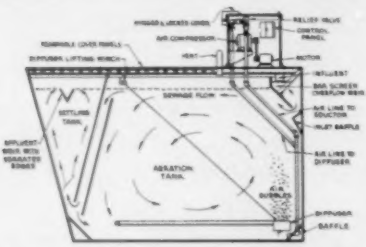
SEWAGE PUMP STATION

Today's finest pump station. Built from the most advanced design, by skilled factory-trained personnel, using quality materials and equipment.

Precision assembled, central electrical control cabinet prewired and color coded, dehumidified interior to prevent condensation. Pumps have pressurized mechanical seals. Low in initial cost and easy to install. Smith & Loveless stations are designed to provide maximum efficiency and long life with a minimum of maintenance.

Smith & Loveless offer a complete line of standard size factory-built lift stations with capacities up to 4500 G.P.M.



Smith & Loveless **"OXIGEST"**
SEWAGE TREATMENT PLANT

A high-quality, low-cost sewage treatment plant for sub-divisions, schools, motels and industrial plants. The "Oxigest" plant has been carefully engineered for dependable treatment without requiring the services of a skilled operator. Approved by F.H.A. and State Health Departments where submitted.

Built of the finest materials and properly reinforced to withstand interior and exterior pressures. The Smith & Loveless "Oxigest" will provide a permanent plant with minimum annual maintenance. Smith & Loveless also provide a complete line of "Sy-No-Seal" rotary distributors and other sewage treatment equipment.

Write for Smith & Loveless "Oxigest" data manual with design notes, specifications, drawings, etc.

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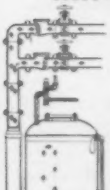
"WAY-O-MATIC"
FACTORY-BUILT
SEWAGE EJECTOR

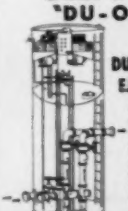


Ideal for installations requiring 200 G.P.M. or less. The "Way-O-Matic" Ejector practically eliminates maintenance as the sewage does not come into contact with any of the controls. Built of finest materials to provide maximum performance at factory-built prices. The "Way-o-matic" may be ordered as a separate unit or in a complete lift station. Cutaway drawing shows operating principle.

Smith & Loveless
"MON-O-JECT"
FACTORY-BUILT
SINGLE PNEUMATIC EJECTOR STATION

Designed for small installations of 200 G.P.M. or less. Completely automatic, extra large air storage. Requires minimum maintenance. Built of the finest materials and meeting the same high standards set by all Smith & Loveless lift stations. The "Mon-O-Ject" provides high-quality equipment for the modest budget. Requires minimum space underground. Cutaway drawing shows construction details.

Smith & Loveless
"DU-O-JECT"
FACTORY-BUILT
DUPLEX PNEUMATIC EJECTOR STATION



Most small sewage lift projects are served most economically and dependably by the Smith & Loveless "Mon-o-ject" single pneumatic sewage ejector lift stations. Where duplex equipment must be provided, the Smith & Loveless "Du - O - Ject" meets the requirements most economically. Cutaway drawing shows construction details.

ALL S&L PRODUCTS ARE PERMANENTLY PROTECTED WITH S&L "VERSAPOX" EPOXY COATINGS

MAKERS OF WATER AND SEWAGE TREATMENT EQUIPMENT

S&L *Smith & Loveless, Inc.*

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REPRESENTATIVES IN PRINCIPAL CITIES

For job recommendations, complete specifications, dimension drawings, capacity charts, etc., all part of the latest Smith & Loveless lift station data manual.

WRITE DEPT. 30D

No obligation.

N. Y., acted as moderator. Participating were: J. M. Whalen, Plant Operator, International Business Machines Corp.; Vincent Traina, Sanitary Engineer, Republic Steel Corp.; Carl G. Mauriello, Plant Operator, Lederle Laboratories, American Cyanamid Co.; Thomas Tully, Process Engineer, General Electric Co.; Frederick E. Ray, Supervisor—Process Service, Refinery Engineering Div., Socony-Mobile Oil Co., Inc.; and Arthur H. Klein, Sanitary Engineer, Wyoming County Health Department.

RALPH C. SWEENEY,
Executive Secretary

NEW JERSEY SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 43rd Annual Meeting of the New Jersey Sewage and Industrial Wastes Association was held at the Hotel Traymore, Atlantic City, N. J., on March 12–14, 1958. Attendance totaled 507. The number of industrial wastes men in attendance increased from 21 in 1957 to 47 in 1958—a trend which the Association is pleased to note.

One of the highlights of the meeting was a Neutralization Symposium. A number of interesting papers were also presented, including discussions on the basis for state and interstate regulations on discharge of industrial wastes, legal aspects of stream pollution, basic data for chemical waste disposal, and disposal of cyanide wastes.

Louis J. Fontenelli, Rahway Valley Joint Meeting, was the recipient of the 1957 Bedell Award for outstanding service to the Association. Anthony J. Macri, Superintendent of the Sewage Treatment Plant, Hammonton, received the Hatfield Award for outstanding

(*Continued on page 370a*)

SEWAGE TREATMENT PLANT ENGINEERS

(CIVIL SERVICE POSITIONS)

The City of Nashville, Tennessee, is accepting applications for the following positions:

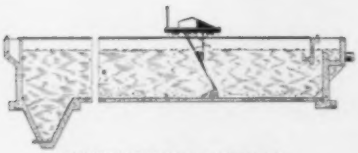
Sewage Disposal and Treatment Engineer. Graduate Sanitary Engineer or Civil or Chemical Engineer with six years experience in sewage treatment plant; age 28 to 45 years old; salary $7500 to $8200 year.

Assistant Sewage Disposal and Treatment Engineer. Same qualifications as above only with four years experience and age 26 to 45 years; salary $6000 to $6600 year.

Chief Sewage Chemist. Graduate Chemist with 5 years full time experience in analytical work in sewage treatment; age 26 to 45 years; salary $5100 to $6000 year.

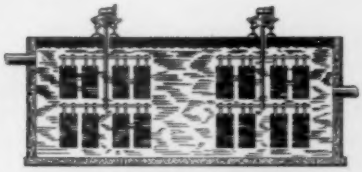
All of the above under Civil Service with liberal pension, vacation and sick leave benefits. If called for interview City will pay travel and reasonable incidental expenses. Write giving education, experience, references and personal data to Nashville Civil Service Commission, 305 City Hall, Nashville 3, Tennessee.

WATER, SEWAGE AND TRADE-WASTE TREATING EQUIPMENT



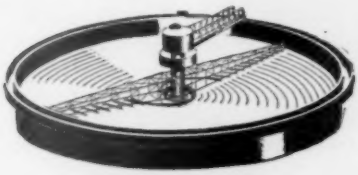
RECTANGULAR CLARIFIERS

Especially suited for limited spaces or where sludge delivery is desired at one end of the tank. A traveling scraper and skimmer carriage removes settled solids from the tank bottom and scum from the top.



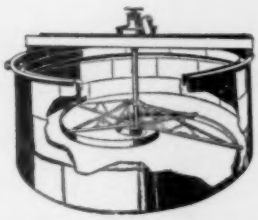
FLOCCULATING UNITS

Slowly rotating paddles on vertical shafts bring the small flocs into contact to form larger masses and hasten precipitation.



CIRCULAR CLARIFIERS

Hardinge Circular Clarifiers are available in sizes up to 200' diameter, either center-column or beam supported for steel, concrete, wood or tile tanks. Sludge scrapers remove settled solids rapidly through central underflow discharge.

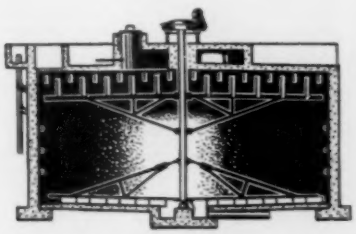


"AUTO-RAISE" THICKENERS

For removal of fine suspended solids from supply water, waste water and sewage. "Auto-Raise" mechanism prevents scraper breakage. Manual or power raise supplements "Auto-Raise." Replaceable ring-type ball bearing support for rotating mechanism. Spiral rakes for maximum underflow density.

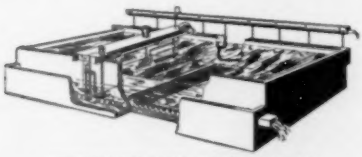
HYDRO-CLASSIFIERS

A large-volume classifier for rapid separation of coarse and fine suspended solids. Frequently used for by-product recovery from waste water.



DIGESTERS

Sludge scrapers and scum breaker arms prevent scum accumulation, insure uniform gas production. Emit a dense digested sludge.



AUTOMATIC BACKWASH FILTERS

For high removal of non-settling or slow settling suspended matter. Self-cleaning sand bed. No shut-down necessary for backwashing. Traveling backwash mechanism.

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2nd Vice-President: Michael S. Kachorsky, Manville.

Treasurer: Henry Van Der Vliet, Rutherford.

Secretary: Anthony T. Leahy, West Trenton.

ANTHONY T. LEAHY,
Secretary

ARKANSAS WATER AND SEWAGE CONFERENCE

The 27th Annual Meeting of the Arkansas Water and Sewage Conference was held at the University of Arkansas, Fayetteville, Ark., March 24–26, 1958. There were 216 registrants, a new record for Fayetteville.

Officers for 1958–59 are:

Chairman: Nall Brantley, Forrest City.

Vice-Chairman: Marion Ulmer, Jonesboro.

FSIWA Director: M. L. Wood, Little Rock.

Secretary-Treasurer: C. W. Oxford, Fayetteville.

C. W. OXFORD
Secretary-Treasurer

KANSAS SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The Kansas Sewage and Industrial Wastes Association held its 13th Annual Joint Meeting with the Kansas Section AWWA, at the Lamar Hotel, Salina, Kans., March 12–14, 1958. Of the total registration of 233, approximately 80 represented the Sewage and Industrial Wastes Section.

A highlight of the meeting was the panel discussion on "Sewage Treat-

(*Continued on page 372a*)

CEN-VI-RO PIPE TAKES TO THE AIR

CEN-VI-RO Concrete Pipe provides economical installation on piers.

Either above or below ground, CEN-VI-RO pipe protects against leaks or infiltration.

The CEN-VI-RO process develops high density concrete with low absorption.

Twelve-foot lengths, with joints sealed by "O"-ring rubber gaskets, make installation costs lower.

GRAY CONCRETE PIPE COMPANY, INC.

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Wilson, N. C. **Baltimore, Md.**
Hagerstown, Md.

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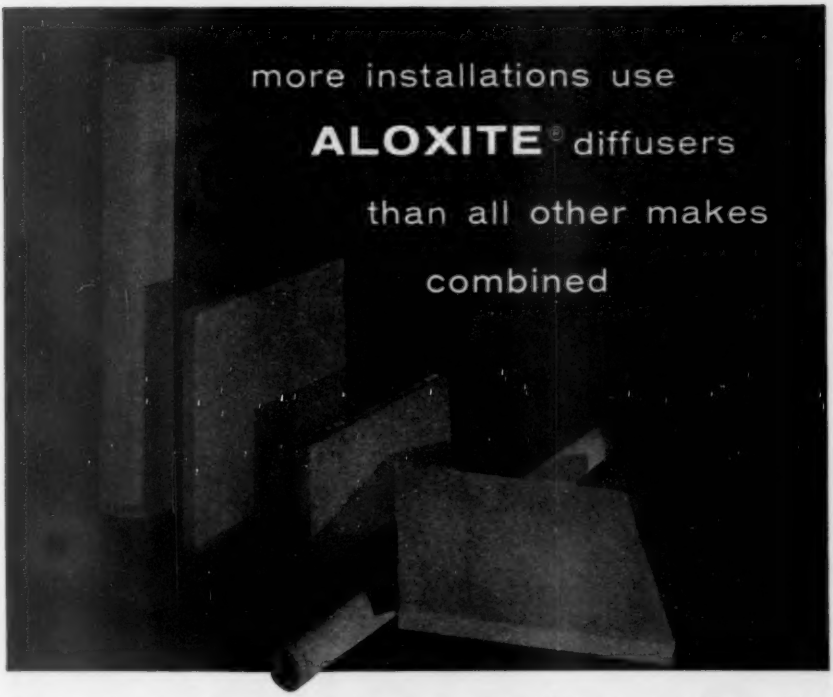

Since the discovery of the activated sludge process (in 1915) only one diffuser material has stood the test of time. Only porous ceramic diffusers have been used with continued success. And more installations have been made with ALOXITE® aluminum oxide diffusers than all other makes combined. Hundreds are in operation—many after over 20 years' service. Here are 5 reasons why:

1. A highly uniform grain structure in ALOXITE diffuser plates and tubes assures a uniform, small-bubble diffusion. That means optimum oxygen absorption.

2. ALOXITE diffusers have a relatively smooth surface. This fact, coupled with the glass-like ceramic bond that coats each grain, minimizes pressure loss and clogging.

3. ALOXITE diffusers never lose their corrosion resistance.

4. ALOXITE diffuser plates and tubes are adaptable to virtually every cleaning method.

5. ALOXITE diffusers have great strength and ruggedness for long life.

ALOXITE diffusers are available in plate or tube form, and in a full variety of grades. This permits maximum flexibility of design. It also lets you select the exact grade for a given function (consistent with air supply quality, pressure loss characteristics, and over-all life). This is particularly important since the introduction of the oxygen absorption test.

ANSWER ALL YOUR QUESTIONS about porous media with this up-to-date 56-page booklet.

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Write to: The Carborundum Company, Refractories Division, Perth Amboy, New Jersey.

ment Plant Design, Maintenance, and Operation." This discussion was moderated by Gordon Mau, Ediger Engineering Co., Wichita. Participating were: Dean Bolick, F. O. Doty and Sons, Pittsburg, and John Glidewell, Sewage Treatment Plant, Topeka.

The technical sessions included interesting papers on the following subjects: gas recirculation for scum control in digestors, conditioning of boiler water, bearings and their lubrication, and preparation and painting of surfaces in sewage plants.

Officers elected for 1958–59 were:

Chairman: Stanley W. Smith, Salina.
1st Vice-Chairman: W. K. Moffatt, Chanute.
2nd Vice-Chairman: Chester L. Goble, Hutchinson.
Secretary-Treasurer: James F. Aiken, Jr., Wichita.

JAMES F. AIKEN, JR.
Secretary-Treasurer

CALIFORNIA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 30th Annual Conference of the California Sewage and Industrial Wastes Association was held at the Hotel Stockton, Stockton, Calif., April 23–26, 1958. The North San Joaquin Section of the California Association was host at this meeting which was attended by 410 members and guests.

The technical program was well balanced and generally excellent. Full and effective use was made of the breakfast session plan and four such sessions were held.

The Bedell Award was presented to A. A. Appel of Los Angeles for extraordinary personal service to the California Association. The Hatfield Award for outstanding sewage works

(*Continued on page 374a*)

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★ Sewer Rods ★ Sectional Steel Rods
★ Complete Sewer Cleaning Machines
★ Braces and Guides
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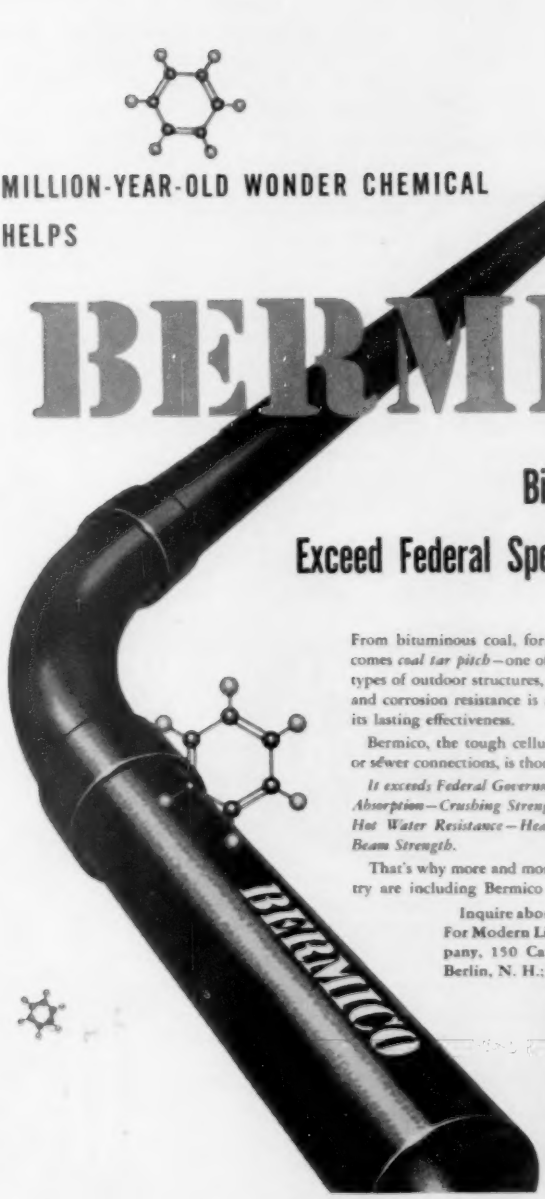

From bituminous coal, formed by Nature millions of years ago, comes *coal tar pitch*—one of the wonder chemicals of today. On all types of outdoor structures, roads, roofs—wherever successful water and corrosion resistance is a *must*—there *coal tar pitch* has proved its lasting effectiveness.

Bermico, the tough cellulose fibre pipe, for house-to-septic tank or sewer connections, is thoroughly impregnated with *coal tar pitch*.

It exceeds Federal Government performance requirements for Water Absorption—Crushing Strength—Chemical and Kerosene Resistance—Hot Water Resistance—Heat Resistance—Resistance to Flattening—Beam Strength.

That's why more and more code authorities throughout the country are including Bermico bituminized fibre pipe in their codes.

Inquire about new full-color movie: "Modern Pipe For Modern Living." Write Dept. JB-9, Brown Company, 150 Causeway St., Boston 14, Mass. (Mills: Berlin, N. H.; Corvallis, Ore.)

Speed up installation with:
BERMICO®
for house to sewer or septic tank
BERMISEPTIC®
for septic tank disposal fields

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operation reports went to E. O. Sampson of Oceanside. FSIWA President Kenneth S. Watson made the presentation.

Officers elected for 1957–58 were:

President: Robert D. Bargman, Los Angeles.
1st Vice-President: P. H. McGauhey, Richmond.
2nd Vice-President: D. A. O'Leary, San Diego.
FSIWA Director (1961): Harvey H. Hunt, Los Angeles.
Secretary-Treasurer: Alfred D. Leipzig, Venice.

ALFRED D. LEIPZIG,
Secretary-Treasurer

VIRGINIA INDUSTRIAL WASTES AND SEWAGE WORKS ASSOCIATION

The 12th Annual Meeting of the Virginia Industrial Wastes and Sewage age Works Association was held at the Hotel Roanoke, Roanoke, Va., April 28–29, 1958. A total of 138 members and guests attended.

The technical program was well balanced and excellent papers were presented in both sewage and industrial wastes areas of interest. The panel discussion on digester operation was one of the highlights of the meeting.

FSIWA Vice-President William D. Hatfield represented the Federation Headquarters and spoke on plant operation in the presence of industrial wastes.

At the business meeting the following officers were elected for 1958–59:

President: Edward H. Ruehl, Richmond.
Vice-President: A. H. Paessler, Richmond.
Secretary-Treasurer: Orval J. Hand, Hopewell.

ORVAL J. HAND,
Secretary-Treasurer

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Type "SW-O" shown, is directly submerged in material to be pumped. Free of packing and bearing troubles. Rendering outstanding service in important processing and sewage treatment plants, mines and mills. One of many NAGLE SEWAGE PUMPS shown in CATALOG 5206.

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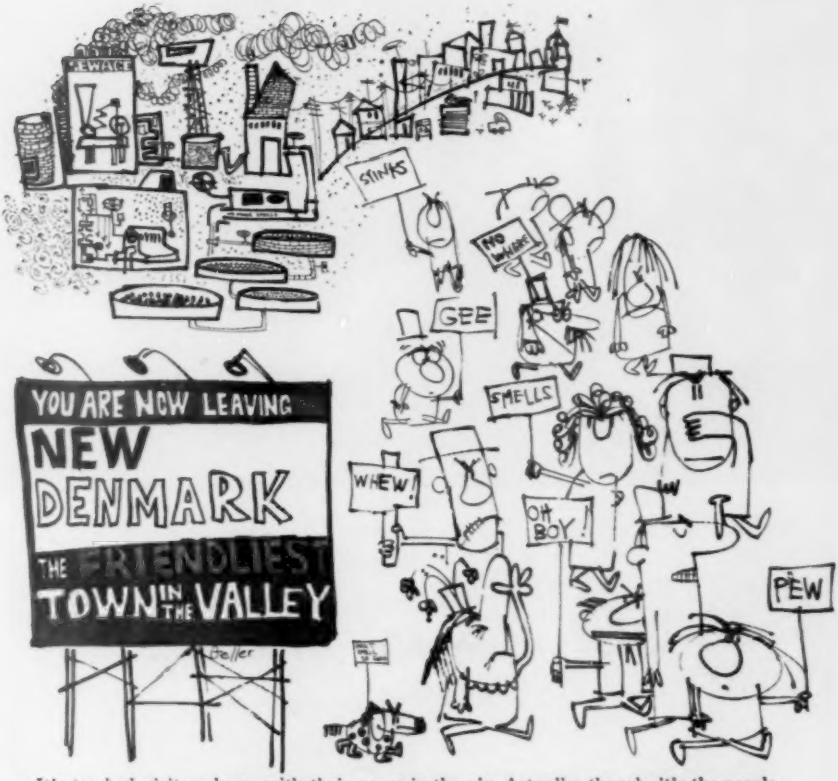

It's too bad visitors leave with their noses in the air. Actually, though, it's the people you live with the year-round whom you should be concerned about.

Sure, obnoxious sewage odors are nothing new to lots of people. But it's easy to get into a complacent rut about how intensely people feel about foul odors.

It's equally easy to get rid of foul sewage odors before popular clamor gets too thick. **ALAMASK®** odor-neutralizing chemicals prevent the obnoxious odors of sewage disposal plants, and do it *better, easier* and at *less cost* than other methods. We can prove this to you by giving your sewage disposal plant a *free* odor-control survey. Take us up on this offer. Call or write us now. Technical literature available, of course.

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31st Annual Meeting

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HOST ASSOCIATION—THE MICHIGAN SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

SHERATON-CADILLAC HOTEL OCTOBER 6-9, 1958

DETROIT, MICHIGAN

NEW VISTAS

During this past year we have continued to manufacture and place in operation Coilfilter installations at the same heavy pace as for the previous 4 years.

As in 1957 a large percentage of this work is repeat order business; Consulting Engineers who have used our equipment have come to realize the performance that is built into the Coilfilter design and the high caliber of service rendered by our field crews.

As far as research is concerned most of this has been of a practical nature in inquiring further into the possible advantages, and drawbacks, of fresh solids dewatering. Actual operating experience in the field has been very good and the question of pathogenicity has been largely resolved. Material on this phase of our work will be reported in Technical Publications and promises to be the next big advance in the practice of Sanitary Engineering.

We are pleased to know that the auxiliary equipment developed by us through the years, involving mainly the chemical feeders and sludge pumps, are operating with complete satisfaction in numerous installations. This phase of our activity has generated more confidence among Engineers in mechanical sludge dewatering.

Again we wish to express our appreciation to the Sanitary Field for the work we have been permitted to do during this most successful year.

As far as the future is concerned, it would appear that there is plenty of work for those who lead.

Respectfully,
T. R. Komline

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Polyvinyl Chloride Pipe—A comprehensive 30-page catalog, prepared for the design engineer, is now available on the characteristics of polyvinyl chloride pipe (PVC).—A. M. Byers Co., Pittsburgh 22, Pa.

Sluice Gates—Illustrated 4-page Bulletin G-12457 describes a complete line of sluice gates for water and sewage flow control.—Armco Drainage and Metal Products, Inc., Middletown, Ohio.

Chlorinator.—A new V-notch chlorinator with capacity up to 8,000 lb per 24 hr is described in recent releases on Series A-721 chlorinating equipment.—Wallace and Tiernan Inc., 25 Main St., Belleville 9, N. J.

Agitator Blades—Light-weight plastic agitator blades for corrosion-resistant service are described in current releases.—Haveg Industries, Inc., 900 Greenbank Rd., Wilmington 8, Del.

Audio-Tone Control Systems—Bulletin 240-P4 details data on transistorized audio-tone transmission systems for telemetering and control.—Builders-Providence, Inc., 345 Harris Ave., Providence, R. I.

Sewer Cleaning Equipment—Recent releases describe types and application of sewer cleaning equipment.—Champion Corp., Hammond, Ind.

Comminutors—A selection and application handbook on comminutors has been prepared to include considerable data on performance and hydraulic curves.—Worthington Corp., Harrison, N. J.

Cast Iron Pipe—A new catalog on the American Molox ball joint cast iron pipe is currently available. Illustrative material on assembly, weight, and dimensions is included.—American Cast Iron Pipe Co., P. O. Box 2603, Birmingham 2, Ala.

Slurry Feeder—Publication No. TP-10-M describes a self-contained unit for accurate dependable feeding of concentrated slurries.—Wallace and Tiernan, Inc., 25 Main St., Belleville 9, N. J.

Prefabricated Liner—Information is available on a heavy duty asphalt mastic sheet for positive water contaminant in reservoirs, lagoons, canals, etc. The asphalt-saturated felt liners are said to be tough and easily handled. Thickness is ¼ to ½ in., width is 4 ft.—Presstite-Keystone Engineering Products Co., 39th and Couteau Streets, St. Louis, Mo.

Concrete Pressure Pipe—An attractively illustrated booklet presenting the story of concrete pressure pipe (use and design) is available.—Price Brothers Co., 1932 East Monument Ave., Dayton 1, Ohio.

Spectroscope—Bulletin FS-258 describes a sensitive and versatile moderately-priced instrument for spectro-analysis.—Fisher Scientific Co., 717 Forbes St., Pittsburgh 19, Pa.

Blower-Compressor—The "Cyclo-Blower," an axial-flow, positive displacement blower for compression and vacuum service, is described in Bulletin CB-157.—Cyclo/Blower Co., York, Pa.

Grit Handling—A 28-page illustrated, tab indexed booklet contains design data on seven types of grit collectors, two grit washers, and a combination grit collector and mechanical screen.—Book 2571, Link-Belt Co., Dept. PR, Prudential Plaza, Chicago 1, Ill.

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(Continued through page 386a)

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INDEX TO ADVERTISERS

	Page
American Concrete Pressure Pipe Association	359a
American-Marietta Company	365a
American Well Works	358a
Bailey Meter Company	352a
Brown Company	373a
Builders-Providence, Inc., Division of B-I-F Industeries, Inc.	Inside Front Cover
Burgess-Manning Company (Penn Instruments Division)	349a
Carborundum Company (Refractories Division)	354a
Cast Iron Pipe Research Association	371a
Chain Belt Company	338a, 339a
Chapman Valve Manufacturing Company	340a
Chicago Pump Company	356a, 357a
Combustion Engineering Company	351a
Dorr-Oliver Incorporated	353a
Flexible Incorporated	362a
General Chemical Division (Allied Chemical Corporation)	388a
Graver Water Conditioning Company	342a
Gray Concrete Pipe Company, Incorporated	363a
Hardinge Company, Incorporated	370a
Infilco Incorporated	369a
Iowa Valve Company (Subsidiary of James B. Clow and Sons)	337a
Komline-Sanderson Engineering Corporation	341a
Link-Belt Company	377a
Lock Joint Pipe Company	343a
Nagle Pumps, Incorporated	Inside Back Cover
National Water Main Cleaning Company	374a
Nichols Engineering & Research Corporation	344a
Pacific Flush Tank Company	350a
Rhodia Incorporated	360a
Simplex Valve and Meter Company	375a
Smith and Loveless, Incorporated	335a
Snow Gates and Valves	367a
W. H. Stewart, Incorporated	366a
Vulcan Materials Company	372a
Wallace and Tiernan Incorporated	351a
Wedge-Lock Clay Pipe Manufacturers, Incorporated	Back Cover
Western Machinery Company	355a
Worthington Corporation	364a
Yeomans Brothers Company	345a, 346a, 347a, 348a
	353a

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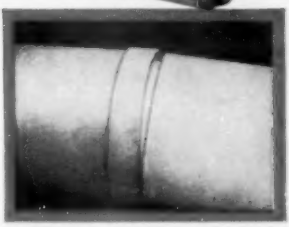

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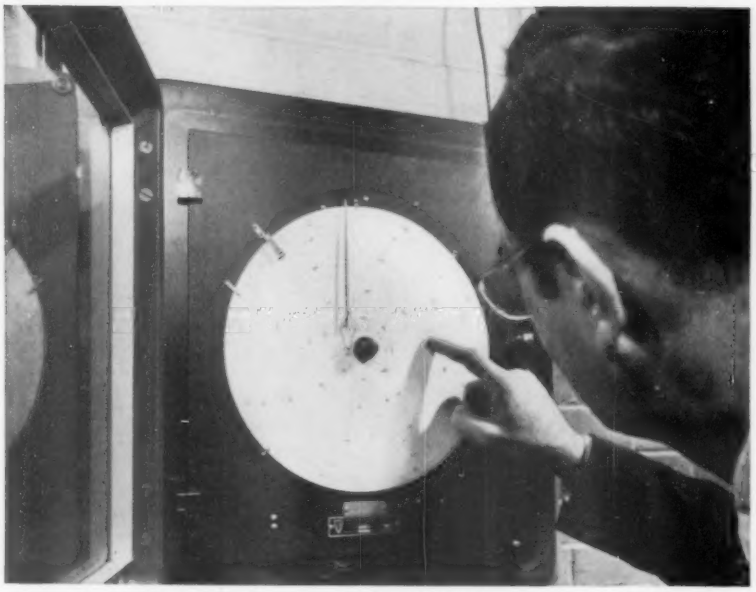

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